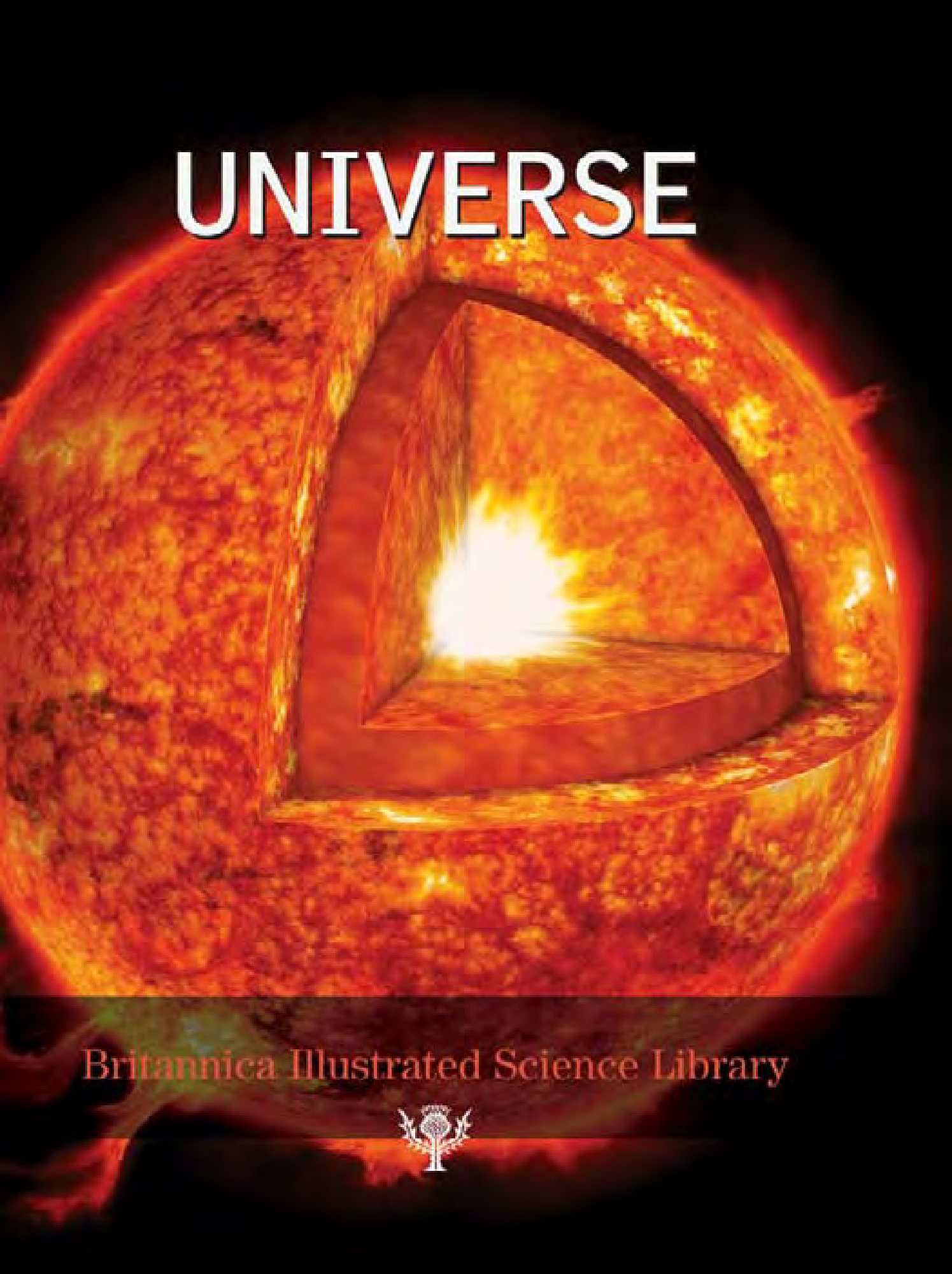
UNIVERSE



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UNIVERSE

Britannica Illustrated Science Library

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Universe

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PICTURE ON PAGE 1
Image of a planetary nebula. Planetary nebulae are among the most photogenic objects in astronomy.

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CONE NEBULA
This nebula got its name from its cone shape, as shown in the image.

The Secrets of the Universe

There was a time when people believed that the stars were bonfires lit by other tribes in the sky, that the universe was a flat plate resting on the shell of a giant turtle, and that the Earth, according to the Greek astronomer Ptolemy, was at the center of the universe. From the most remote of times, people have been curious about what lies hidden beyond the celestial sphere. This curiosity has led them to build telescopes that show with clarity otherwise blurry and distant objects. In this book you will find the history of the cosmos illustrated with spectacular images that show in detail how the cosmos was formed, the nature of the many points of light that adorn the night sky, and what lies ahead. You will also discover how the suns that inhabit space live and die, what dark matter and black holes are, and what our place is in this vastness. Certainly, the opportunity to compare the destiny of other worlds similar to ours will help us understand that for the time being there is no better place than the Earth to live. At least for now.

In the Milky Way—according to mathematical and physical calculations—there are more than 100 billion stars, and such a multitude leads to the question: Is it possible that our Sun is the only star that possesses an inhabited planet? Astronomers are more convinced than ever of the possibility of life in other worlds. We just need to find them. Reading this book will let you become better acquainted with our neighbors in the solar system—the other planets—and the most important characteristics that distinguish them. All this information that explores the mysteries of space is accompanied by recent images captured by the newest telescopes. They reveal many details about the planets and their satellites, such as the volcanoes and craters found on the surface of some of them. You will also learn more about the asteroids and comets that orbit the Sun and about Pluto, a dwarf planet, which is to be visited by a space probe for the first time. Less than a decade ago, astronomers began observing frozen worlds, much smaller than a planet, in a region of the solar system called the Kuiper belt. We invite you to explore all of this. The images and illustrations that accompany the text will prove very helpful in studying and understanding the structure of all the visible and invisible objects (such as dark matter) that form part of the universe. There are stellar maps showing the constellations, the groups of stars that since ancient times have served as a guide for navigation and for the development of calendars. There is also a review through history: from Ptolemy, who thought the planets orbited around the Earth, and Copernicus, who put the Sun in the center, and Galileo, the first to aim a telescope skyward, up to the most recent astronomical theories, such as those of Stephen Hawking, the genius of space and time who continues to amaze with his discoveries about the greatest mysteries of the cosmos. You will find these and many more topics no matter where you look in this fantastic book that puts the universe and its secrets in your hands.

What Is the Universe?

DARK MATTER
Evidence exists that dark matter, though invisible to telescopes, betrays itself by the gravitational pull it exerts over other heavenly bodies.

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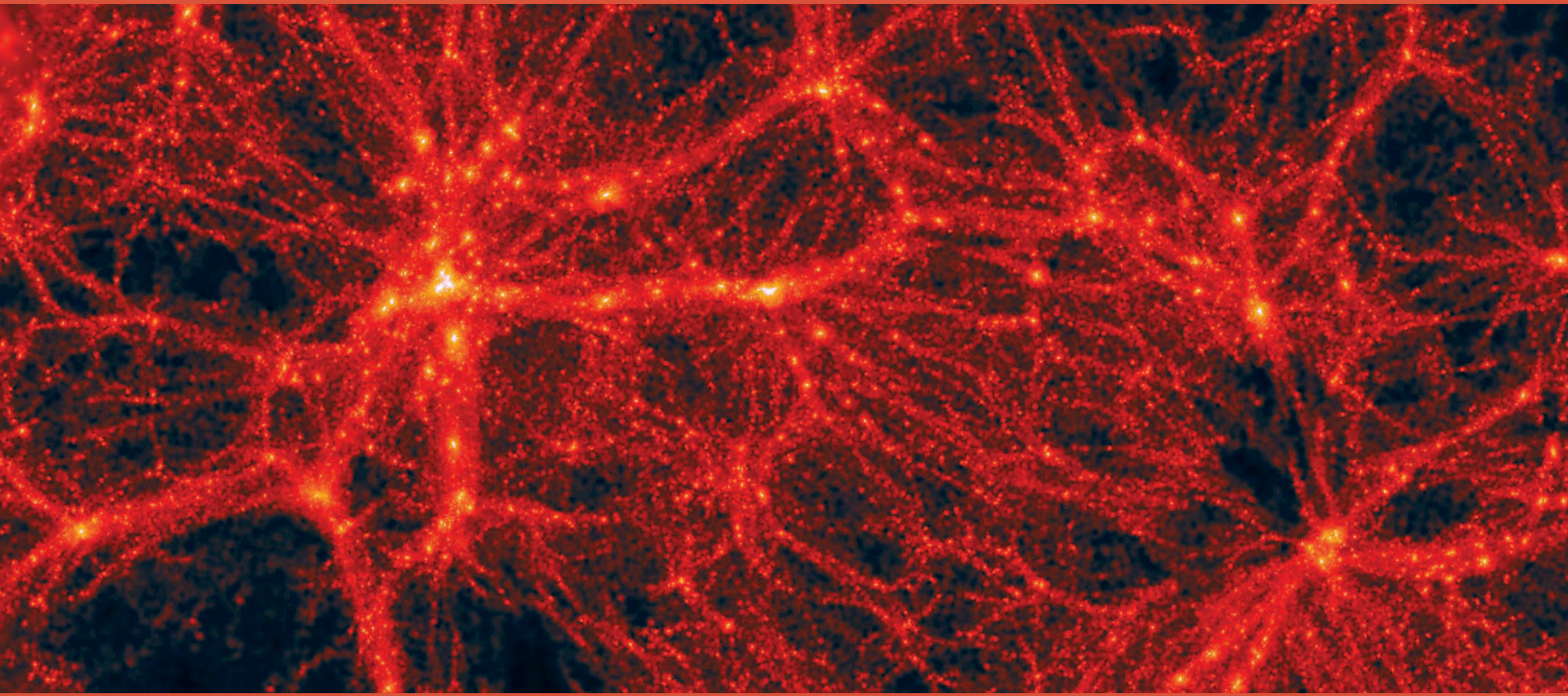


The universe is everything that exists, from the smallest particles to the largest ones, together with all matter and energy. The universe includes visible and invisible things, such as dark matter, the great, secret component of the cosmos. The search for dark matter is currently one of the most important tasks of cosmology. Dark matter may literally determine the density of all of space, as well as decide the destiny of the universe. Did you know that, second by second, the universe grows and grows? The question that astronomers are asking—the question that concerns them the most—is how much longer the universe can continue to expand like a balloon before turning into something cold and dark. ●

X-Ray of the Cosmos

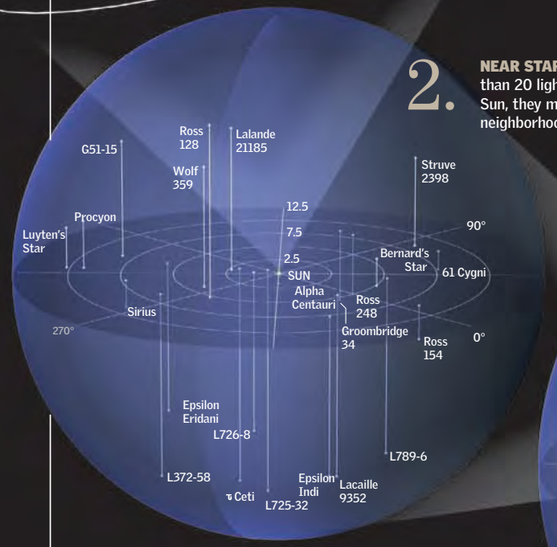
The universe, marvelous in its majesty, is an ensemble of a hundred billion galaxies. Each of these galaxies (which tend to be found in large groups) has billions of stars. These galactic concentrations surround empty spaces, called cosmic voids. The immensity of the cosmos can be better grasped by realizing that the size of our fragile planet Earth, or even that of the Milky Way, is insignificant compared to the size of the remainder of the cosmos.

1.

EARTH Originated, together with the solar system, when the universe was already 9.1 billion years old. It is the only known planet that is home to life.

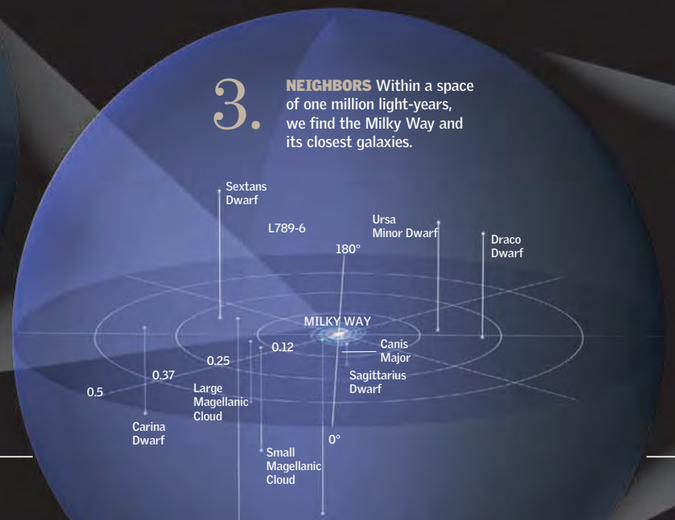
The Universe

Originating nearly 14 billion years ago in an immense explosion, the universe today is too large to be able to conceive. The innumerable stars and galaxies that populate it promise to continue expanding for a long time. Though it might sound strange today, for many years, astronomers thought that the Milky Way, where the Earth is located, constituted the entire universe. Only recently—in the 20th century—was outer space recognized as not only much vaster than previously thought but also as being in a state of ongoing expansion.



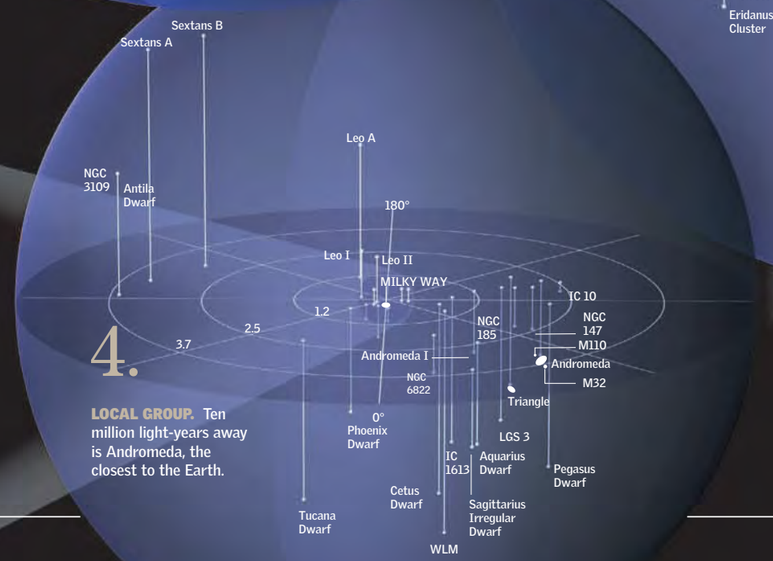
2.

NEAR STARS Found closer than 20 light-years from the Sun, they make up our solar neighborhood.



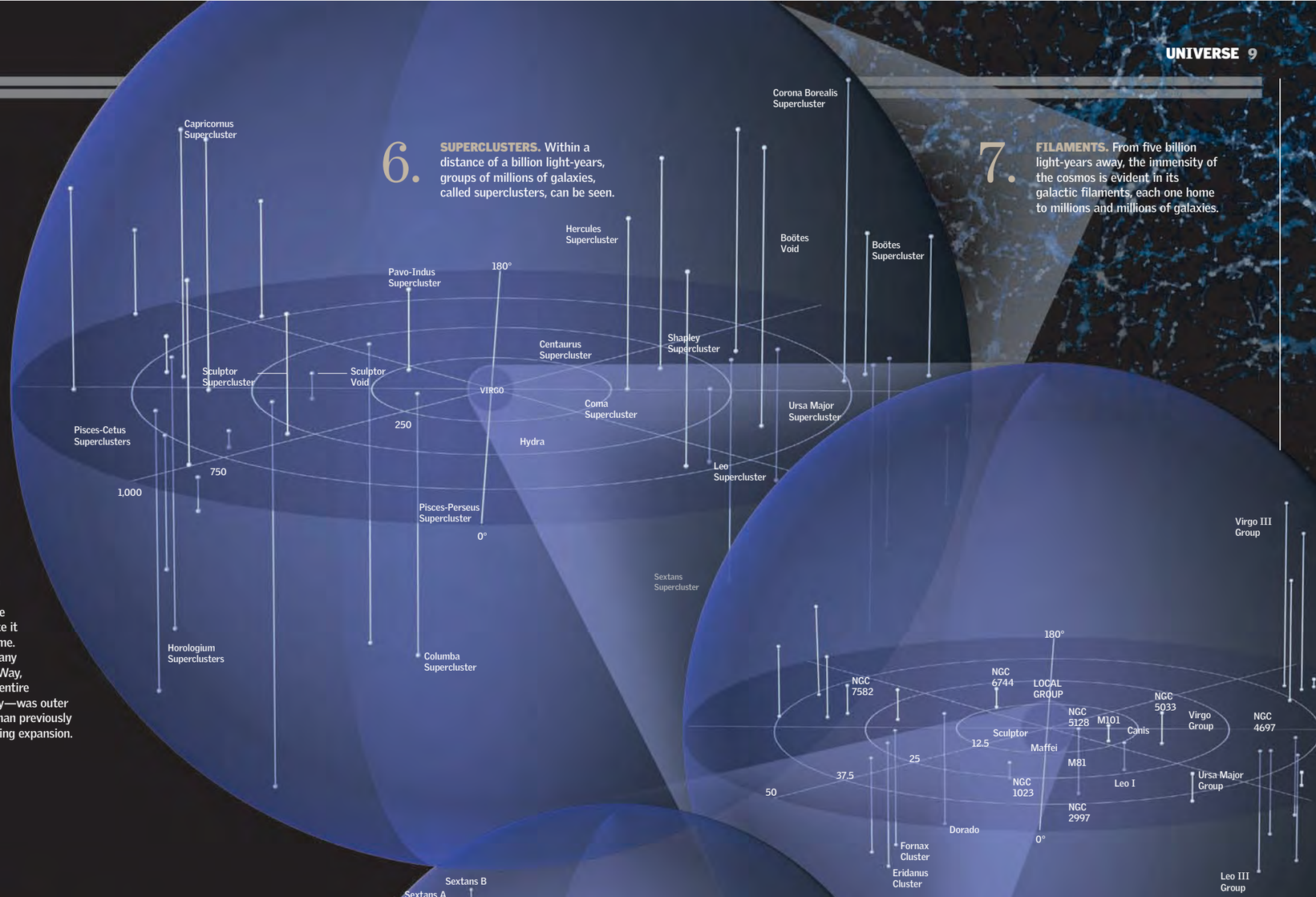
3.

NEIGHBORS Within a space of one million light-years, we find the Milky Way and its closest galaxies.



4.

LOCAL GROUP. Ten million light-years away is Andromeda, the closest to the Earth.



6.

SUPERCLUSTERS. Within a distance of a billion light-years, groups of millions of galaxies, called superclusters, can be seen.

7.

FILAMENTS. From five billion light-years away, the immensity of the cosmos is evident in its galactic filaments, each one home to millions and millions of galaxies.

5.

NEAREST GALAXIES. At a scale of one hundred million light-years, the galactic clusters nearest to the Milky Way can be seen.

100 BILLION

The total number of galaxies that exist, indicating that the universe is both larger and older than was previously thought

The Instant of Creation

It is impossible to know precisely how, out of nothing, the universe began to exist. According to the big bang theory—the theory most widely accepted in the scientific community—in the beginning, there appeared an infinitely small and dense burning ball that gave rise to space, matter, and energy. This happened 13.7 billion years ago. The great, unanswered question is what caused a small dot of light—filled with concentrated energy from which matter and antimatter were created—to arise from nothingness. In very little time, the young universe began to expand and cool. Several billion years later, it acquired the form we know today.

Energetic Radiation

The burning ball that gave rise to the universe remained a source of permanent radiation. Subatomic particles and antiparticles annihilated each other. The ball's high density spontaneously produced matter and destroyed it. Had this state of affairs continued, the universe would never have undergone the growth that scientists believe followed cosmic inflation.

HOW IT GREW

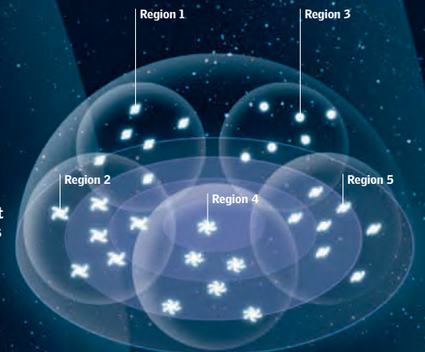
Cosmic inflation was an expansion of the entire universe. The Earth's galactic neighborhood appears fairly uniform. Everywhere you look, the types of galaxies and the background temperature are essentially the same.

Cosmic Inflation Theory

Although big bang theorists understood the universe as originating in an extremely small, hot, and condensed ball, they could not understand the reason for its staggering growth. In 1981, physicist Alan Guth proposed a solution to the problem with his inflationary theory. In an extremely short period of time (less than a thousandth of a second), the universe grew more than a trillion trillion trillion times. Near the end of this period of expansion, the temperature approached absolute zero.

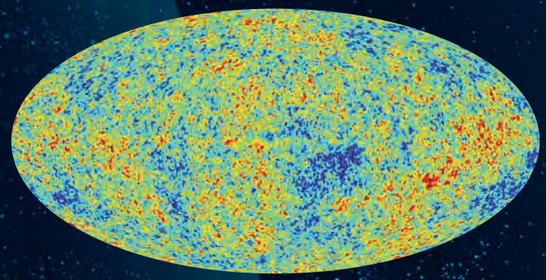
HOW IT DID NOT GROW

Had the universe not undergone inflation, it would be a collection of different regions, each with its own particular types of galaxies and each clearly distinguishable from the others.



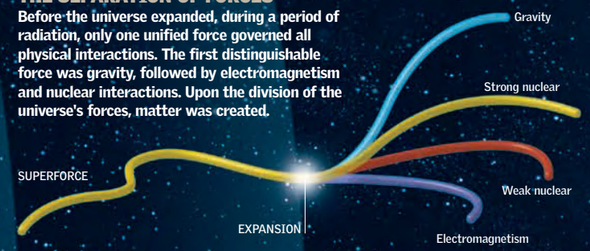
WMAP (WILKINSON MICROWAVE ANISOTROPY PROBE)

NASA's WMAP project maps the background radiation of the universe. In the image, hotter (red-yellow) regions and colder (blue-green) regions can be observed. WMAP makes it possible to determine the amount of dark matter.



THE SEPARATION OF FORCES

Before the universe expanded, during a period of radiation, only one unified force governed all physical interactions. The first distinguishable force was gravity, followed by electromagnetism and nuclear interactions. Upon the division of the universe's forces, matter was created.



TIME 0

TEMPERATURE -

1 Scientists theorize that, from nothing, something infinitely small, dense, and hot appeared. All that exists today was compressed into a ball smaller than the nucleus of an atom.

10^{-43} sec

10^{32} ° F (and C)

2 At the closest moment to zero time, which physics has been able to reach, the temperature is extremely high. Before the universe's inflation, a superforce governed everything.

10^{-38} sec

10^{29} ° F (and C)

3 The universe is unstable. Only 10^{-38} seconds after the big bang, the universe increases in size more than a trillion trillion trillion times. The expansion of the universe and the division of its forces begin.

10^{-12} sec

10^{15} ° F (and C)

4 The universe experiences a gigantic cooldown. Gravity has already become distinguishable, and the electromagnetic force and the strong and weak nuclear interactions appear.

10^{-4} sec

10^{12} ° F (and C)

5 Protons and neutrons appear, formed by three quarks apiece. Because all light is trapped within the web of particles, the universe is still dark.

5 sec

$9x10^{9}$ ° F ($5x10^{9}$ ° C)

6 The electrons and their antiparticles, positrons, annihilate each other until the positrons disappear. The remaining electrons form atoms.

3 min

$2x10^{9}$ ° F ($1x10^{9}$ ° C)

7 The nuclei of the lightest elements, hydrogen and helium, form. Protons and neutrons unite to form the nuclei of atoms.

ELEMENTARY PARTICLES

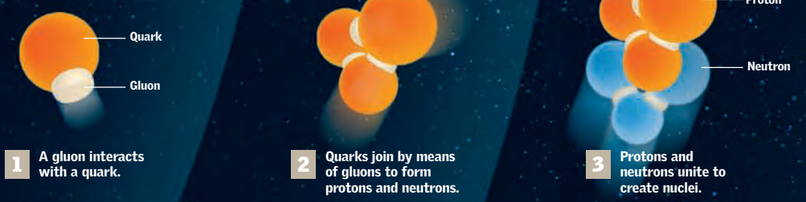
In its beginnings, the universe was a soup of particles that interacted with each other because of high levels of radiation. Later, as the universe expanded, quarks formed the nuclei of the elements and then joined with electrons to form atoms.

1 sec

The neutrinos separate from the initial particle soup through the disintegration of neutrons. Though having extremely little mass, the neutrinos might nevertheless form the greatest part of the universe's dark matter.

FROM PARTICLES TO MATTER

The quarks, among the oldest particles, interact with each other by forces transmitted through gluons. Later protons and neutrons will join to form nuclei.



1 A gluon interacts with a quark.

2 Quarks join by means of gluons to form protons and neutrons.

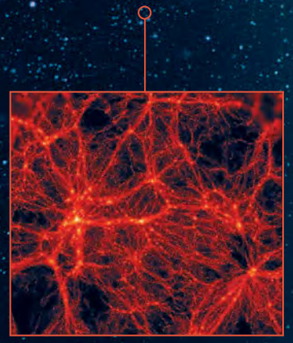
3 Protons and neutrons unite to create nuclei.

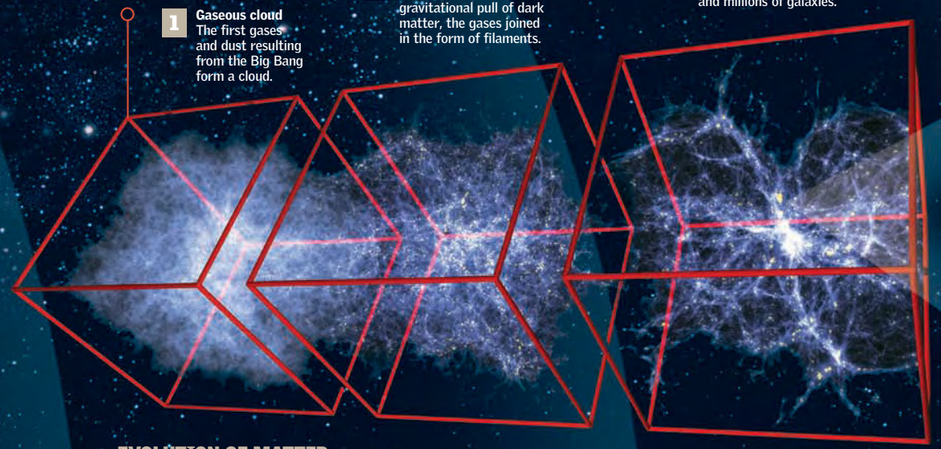
The Transparent Universe

With the creation of atoms and overall cooling, the once opaque and dense universe became transparent. Electrons were attracted by the protons of hydrogen and helium nuclei, and together they formed atoms. Photons (massless particles of light) could now pass freely through the universe. With the cooling, radiation remained abundant but was no longer the sole governing factor of the universe. Matter, through gravitational force, could now direct its own destiny. The gaseous lumps that were present in this process grew larger and larger. After 100 million years, they formed even larger objects. Their shapes not yet defined, they constituted protogalaxies. Gravitation gave shape to the first galaxies some 500 million years after the big bang, and the first stars began to shine in the densest regions of these galaxies. One mystery that could not be solved was why galaxies were distributed and shaped the way they were. The solution that astronomers have been able to find through indirect evidence is that there exists material called dark matter whose presence would have played a role in galaxy formation.

DARK MATTER

The visible objects in the cosmos represent only a small fraction of the total matter within the universe. Most of it is invisible even to the most powerful telescopes. Galaxies and their stars move as they do because of the gravitational forces exerted by this material, which astronomers call dark matter.





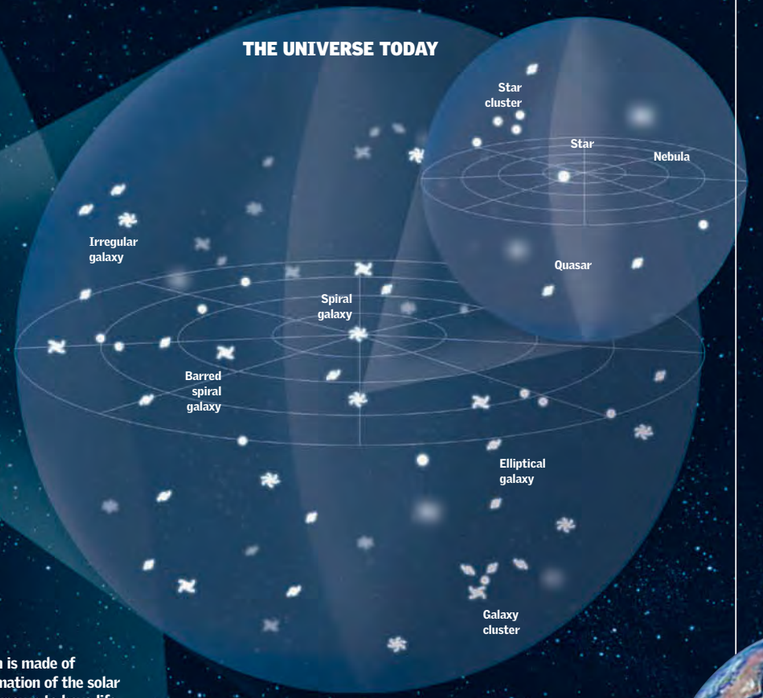
1 Gaseous cloud
The first gases and dust resulting from the Big Bang form a cloud.

2 First filaments
Because of the gravitational pull of dark matter, the gases joined in the form of filaments.

3 Filament networks
The universe has large-scale filaments that contain millions and millions of galaxies.

EVOLUTION OF MATTER

What can be observed in the universe today is a great quantity of matter grouped into galaxies. But that was not the original form of the universe. What the big bang initially produced was a cloud of uniformly dispersed gas. Just three million years later, the gas began to organize itself into filaments. Today the universe can be seen as a network of galactic filaments with enormous voids between them.



9.1 billion

THE EARTH IS CREATED

Like the rest of the planets, the Earth is made of material that remained after the formation of the solar system. The Earth is the only planet known to have life.

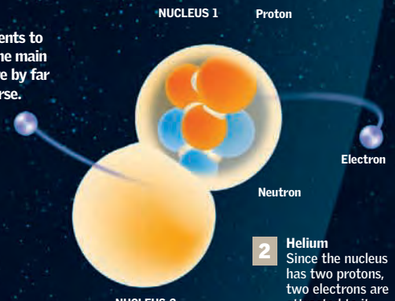
TIME (in years) **380,000**

TEMPERATURE **4,900° F (2,700° C)**

8 380,000 years after the big bang, atoms form. Electrons orbit the nuclei, attracted by the protons. The universe becomes transparent. Photons travel through space.

FIRST ATOMS

Hydrogen and helium were the first elements to be formed at the atomic level. They are the main components of stars and planets. They are by far the most abundant elements in the universe.



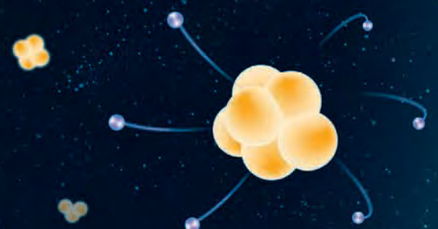
1 Hydrogen
An electron is attracted by and orbits the nucleus, which has a proton and a neutron.

2 Helium
Since the nucleus has two protons, two electrons are attracted to it.

500 million

-405° F (-243° C)

9 Galaxies acquire their definitive shape: islands of millions and millions of stars and masses of gases and dust. The stars explode as supernovas and disperse heavier elements, such as carbon.



3 Carbon
With time, heavier and more complex elements were formed. Carbon, the key to human life, has six protons in its nucleus and six electrons orbiting it.

9 billion

-432° F (-258° C)

10 Nine billion years after the big bang, the solar system emerged. A mass of gas and dust collapsed until it gave rise to the Sun. Later the planetary system was formed from the leftover material.

13.7 billion

-454° F (-270° C)

11 The universe continues to expand. Countless galaxies are surrounded by dark matter, which represents 22 percent of the mass and energy in the universe. The ordinary matter, of which stars and planets are made, represents just 4 percent of the total. The predominant form of energy is also of an unknown type. Called dark energy, it constitutes 74 percent of the total mass and energy.

TIMESCALE

The vast span of time related to the history of the universe can be readily understood if it is scaled to correspond to a single year—a year that spans the beginning of the universe, the appearance of humans on the Earth, and the voyage of Columbus to America. On January 1 of this imaginary year—at midnight—the big bang takes place. *Homo sapiens* appears at 11:56 P.M. on December 31, and Columbus sets sail on the last second of the last day of the year. One second on this timescale is equivalent to 500 true years.

BIG BANG occurs on the first second of the first day of the year.

THE SOLAR SYSTEM is created on August 24 of this timescale.

COLUMBUS'S ARRIVAL takes place on the last second of December 31.

JANUARY

DECEMBER

Everything Comes to an End

The big bang theory helped solve the enigma of the early moments of the universe. What has yet to be resolved is the mystery surrounding the future that awaits. To unravel this mystery, the total mass of the universe must be known, but that figure has not yet been reliably determined. The most recent observations have removed some of this uncertainty. It seems that the mass of the universe is far too little to stop its expansion. If this is this case, the universe's present growth is merely the last step before its total death in complete darkness.

DISCOVERIES
The key discovery that led to the big bang theory was made in the early 1920s by Edwin Hubble, who discovered that galaxies were moving away from each other. In the 1940s, George Gamow developed the idea that the universe began with a primordial explosion. A consequence of such an event would be the existence of background radiation, which Arno Penzias and Robert Wilson accidentally detected in the mid-1960s.

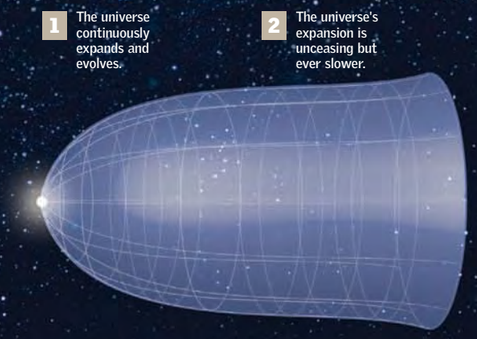
1920s
GALACTIC EXPANSION
By noting a redshift toward the red end of the spectrum, Hubble was able to demonstrate that galaxies were moving away from each other.

1940s
GAMOW'S SUSPICION
Gamow first hypothesized the big bang, holding that the early universe was a "cauldron" of particles.

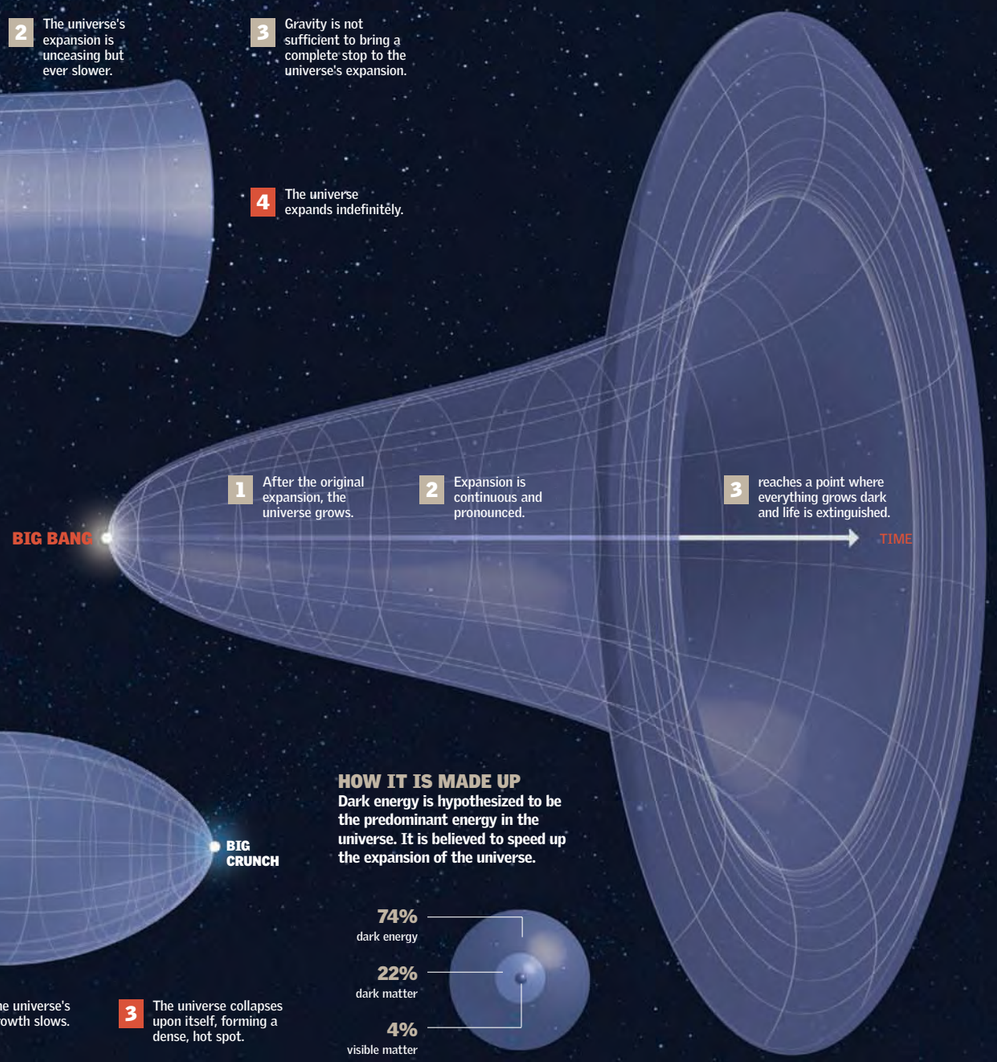
1965
BACKGROUND RADIATION
Penzias and Wilson detected radio signals that came from across the entire sky—the uniform signal of background radiation.

Flat Universe

1 There is a critical amount of mass for which the universe would expand at a declining rate without ever totally stopping. The result of this eternal expansion would be the existence of an ever-increasing number of galaxies and stars. If the universe were flat, we could talk about a cosmos born from an explosion, but it would be a universe continuing outward forever. It is difficult to think about a universe with these characteristics.



THE HAWKING UNIVERSE
The universe was composed originally of four spatial dimensions without the dimension of time. Since there is no change without time, one of these dimensions, according to Hawking, transformed spontaneously on a small scale into a temporal dimension, and the universe began to expand.



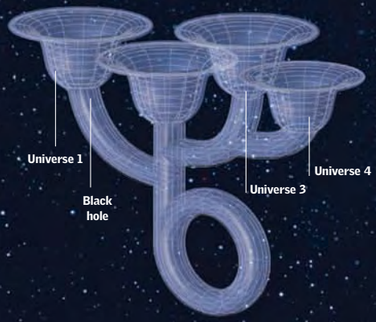
Closed Universe

2 If the universe had more than critical mass, it would expand until reaching a point where gravity stopped the expansion. Then, the universe would contract in the Big Crunch, a total collapse culminating in an infinitely small, dense, and hot spot similar to the one from which the universe was formed. Gravity's pull on the universe's excess matter would stop the expansion and reverse the process.

HOW IT IS MADE UP
Dark energy is hypothesized to be the predominant energy in the universe. It is believed to speed up the expansion of the universe.

Self-generated Universes

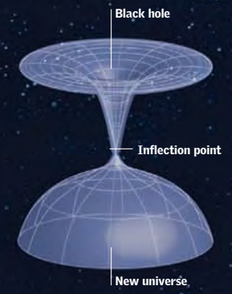
3 A less widely accepted theory about the nature of the universe suggests that universes generate themselves. If this is the case, universes would be created continuously like the branches of a tree, and they might be linked by supermassive black holes.

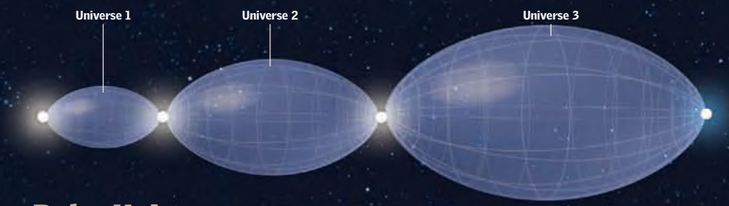


Open Universe

4 The most accepted theory about the future of the cosmos says that the universe possesses a mass smaller than the critical value. The latest measurements seem to indicate that the present time is just a phase before the death of the universe, in which it goes completely dark.

BLACK HOLES
Some theorists believe that, by entering a black hole, travel through space to other universes might be possible because of antigravitational effects.





Baby Universes

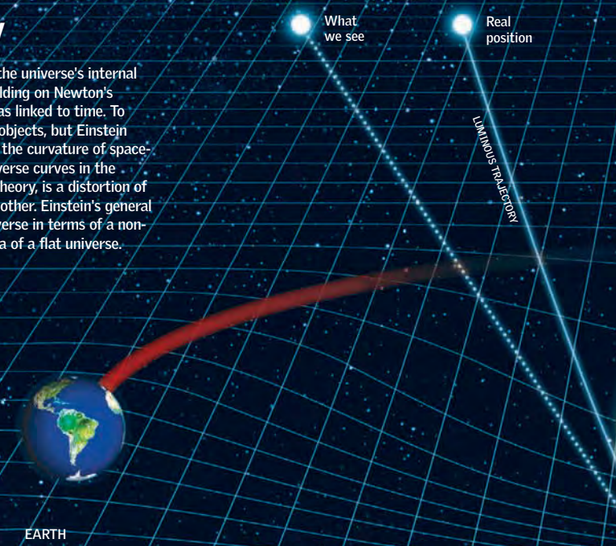
5 According to this theory, universes continuously sprout other universes. But in this case, one universe would be created from the death or disappearance of another. Each dead universe in a final collapse, or Big Crunch, would give rise to a supermassive black hole, from which another universe would be born. This process could repeat itself indefinitely, making the number of universes impossible to determine.

The Forces of the Universe

The four fundamental forces of nature are those that are not derived from basic forces. Physicists believe that, at one time, all physical forces functioned as a single force and that during the expansion of the universe, they became distinct from each other. Each force now governs different processes, and each interaction affects different types of particles. Gravity, electromagnetism, strong nuclear interactions, and weak nuclear interactions are essential to our understanding of the behavior of the many objects that exist in the universe. In recent years, many scientists have tried with little success to show how all forces are manifestations of a single type of exchange.

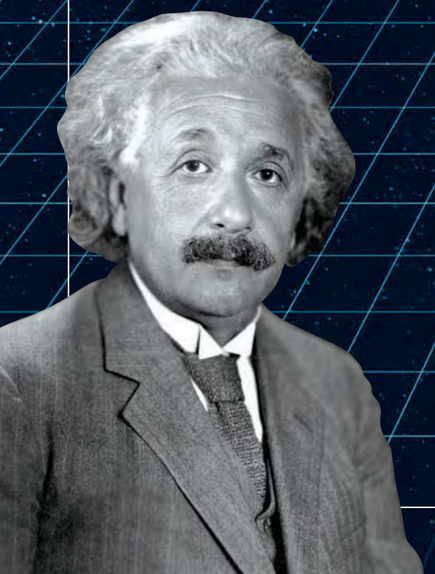
General Theory of Relativity

The biggest contribution to our comprehension of the universe's internal workings was made by Albert Einstein in 1915. Building on Newton's theory of universal gravitation, Einstein thought of space as linked to time. To Newton, gravity was merely the force that attracted two objects, but Einstejn hypothesized that it was a consequence of what he called the curvature of space-time. According to his general theory of relativity, the universe curves in the presence of objects with mass. Gravity, according to this theory, is a distortion of space that determines whether one object rolls toward another. Einstein's general theory of relativity required scientists to consider the universe in terms of a non-Euclidian geometry, since it is not compatible with the idea of a flat universe. In Einsteinian space, two parallel lines can meet.



$$E=mc^2$$

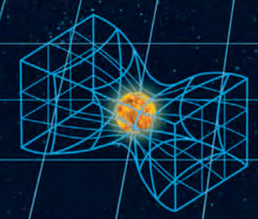
In Einstein's equation, energy and mass are interchangeable. If an object increases its mass, its energy increases, and vice versa.



Gravity

1 **Gravity was the first force to become distinguishable from the original superforce. Today scientists understand gravity in Einstein's terms as an effect of the curvature of space-time. If the universe were thought of as a cube, the presence of any object with mass in space would deform the cube. Gravity can act at great distances (just as electromagnetism can) and always exerts a force of attraction. Despite the many attempts to find antigravity (which could counteract the effects of black holes), it has yet to be found.**

The universe, if it were empty, could be pictured in this way.



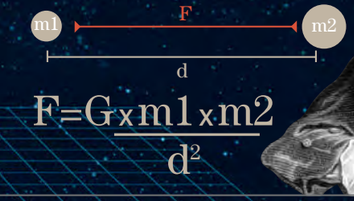
The universe is deformed by the mass of the objects it contains.

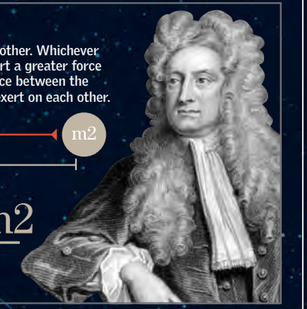
UNIVERSAL GRAVITATION

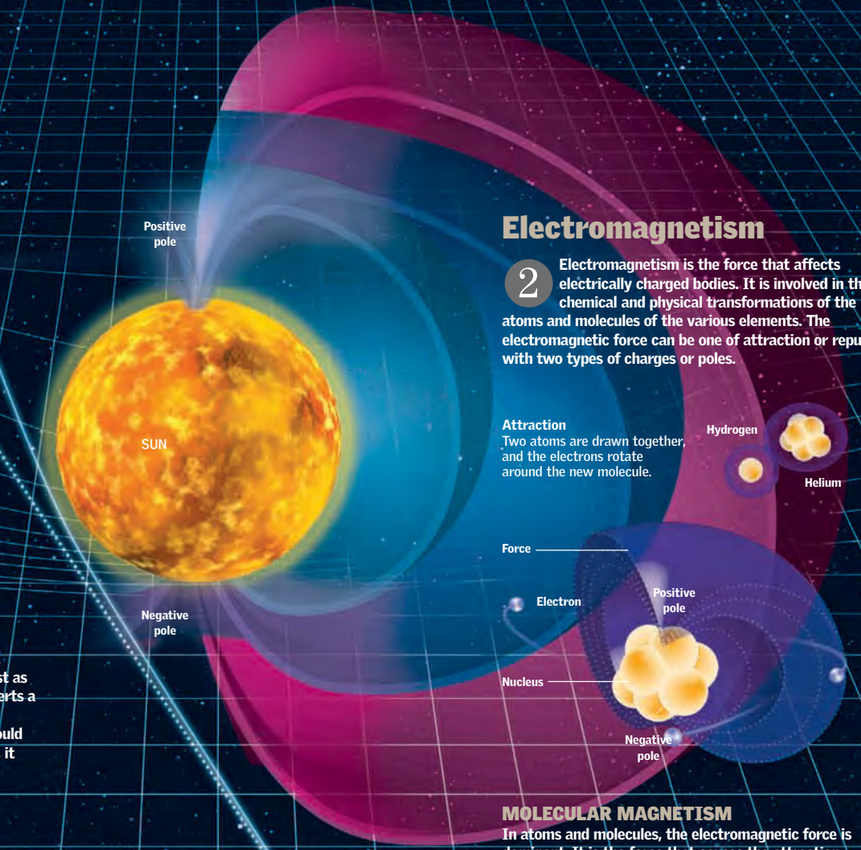
The gravitation proposed by Newton is the mutual attraction between bodies having mass. The equation developed by Newton to calculate this force states that the attraction experienced by two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Newton represented the constant of proportionality resulting from this interaction as G. The shortcoming of Newton's law, an accepted paradigm until Einstein's theory of general relativity, lies in its failure to make time an essential component in the interaction between objects. According to Newton, the gravitational attraction between two objects with mass did not depend on the properties of space but was an intrinsic property of the objects themselves. Nevertheless, Newton's law of universal gravitation was a foundation for Einstein's theory.

NEWTON'S EQUATION

Two bodies with mass attract each other. Whichever body has the greatest mass will exert a greater force on the other. The greater the distance between the objects, the smaller the force they exert on each other.







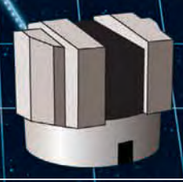
Electromagnetism

2 **Electromagnetism is the force that affects electrically charged bodies. It is involved in the chemical and physical transformations of the atoms and molecules of the various elements. The electromagnetic force can be one of attraction or repulsion, with two types of charges or poles.**

Attraction
Two atoms are drawn together, and the electrons rotate around the new molecule.

MOLECULAR MAGNETISM

In atoms and molecules, the electromagnetic force is dominant. It is the force that causes the attraction between protons and electrons in an atom and the attraction or repulsion between ionized atoms.



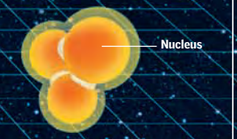
BENDING LIGHT

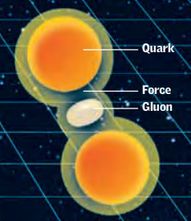
Light also bends because of the curvature of space-time. When seen from a telescope, the real position of an object is distorted. What is perceived through the telescope is a false location, generated by the curvature of the light. It is not possible to see the actual position of the object.

Strong Nuclear Force

3 **The strong nuclear force holds the protons and neutrons of atomic nuclei together. Both protons and neutrons are subject to this force. Gluons are particles that carry the strong nuclear force, and they bind quarks together to form protons and neutrons. Atomic nuclei are held together by residual forces in the interaction between quarks and gluons.**

1 **Quarks and gluons**
The strong nuclear interaction takes place when the gluon interacts with quarks.





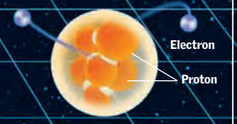
2 **Union**
Quarks join and form nuclear protons and neutrons.

Weak Nuclear Force

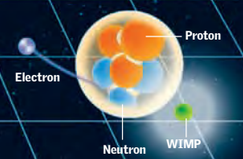
4 **The weak nuclear force is not as strong as the other forces. The weak nuclear interaction influences the beta decay of a neutron, which releases a proton and a neutrino that later transforms into an electron. This force takes part in the natural radioactive phenomena associated with certain types of atoms.**

1 **Hydrogen**
A hydrogen atom interacts with a weak, light particle (WIMP). A neutron's bottom quark transforms into a top quark.

HELIUM ISOTOPE



HYDROGEN ATOM



2 **Helium**
The neutron transforms into a proton. An electron is released, and the helium isotope that is formed has no nuclear neutrons.

What Is in the Universe?

ETA CARINAE NEBULA
With a diameter of more than 200 light-years, it is one of biggest and brightest nebulae of our galaxy. This young, supermassive star is expected to become a supernova in the near future.

LUMINOUS 20-21
STELLAR EVOLUTION 22-23
RED, DANGER, AND DEATH 24-25
GAS SHELLS 26-27
SUPERNOVAE 28-29
THE FINAL DARKNESS 30-31
ANATOMY OF GALAXIES 32-33
ACTIVE GALAXIES 34-35
STELLAR METROPOLIS 36-37

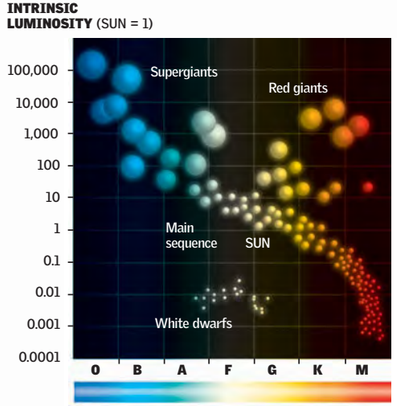
The universe is populated on a grand scale by strands of superclusters surrounding vacant areas. Sometimes the galaxies collide with each other, triggering the formation of stars. In the vast cosmos, there are also quasars, pulsars, and black holes. Thanks to current technology, we can enjoy the displays of light and shadow that make up, for example, the Eta Carinae Nebula (shown), which is composed of jets of hot, fluorescent gases. Although not all the objects in the universe are known, it can be said without a doubt that most of the atoms that make up our bodies have been born in the interior of stars.●

Luminous

For a long time stars were a mystery to humans, and it was only as recently as the 19th century that astronomers began to understand the true nature of stars. Today we know that they are gigantic spheres of incandescent gas—mostly hydrogen, with a smaller proportion of helium. As a star radiates light, astronomers can precisely measure its brightness, color, and temperature. Because of their enormous distance from the Earth, stars beyond the Sun only appear as points of light, and even the most powerful telescopes do not reveal any surface features.

Hertzsprung-Russell (H-R) Diagram

The H-R diagram plots the intrinsic luminosity of stars against their spectral class, which corresponds to their temperature or the wavelengths of light they emit. The most massive stars are those with greatest intrinsic luminosity. They include blue stars, red giants, and red supergiants. Stars spend 90 percent of their lives in what is known as the main sequence.



TYPE O 52,000-72,000° F (29,000-40,000° C)

TYPE B 17,500-52,000° F (9,700-29,000° C)

TYPE A 13,000-17,500° F (7,200-9,700° C)

TYPE F 10,500-13,000° F (5,800-7,200° C)

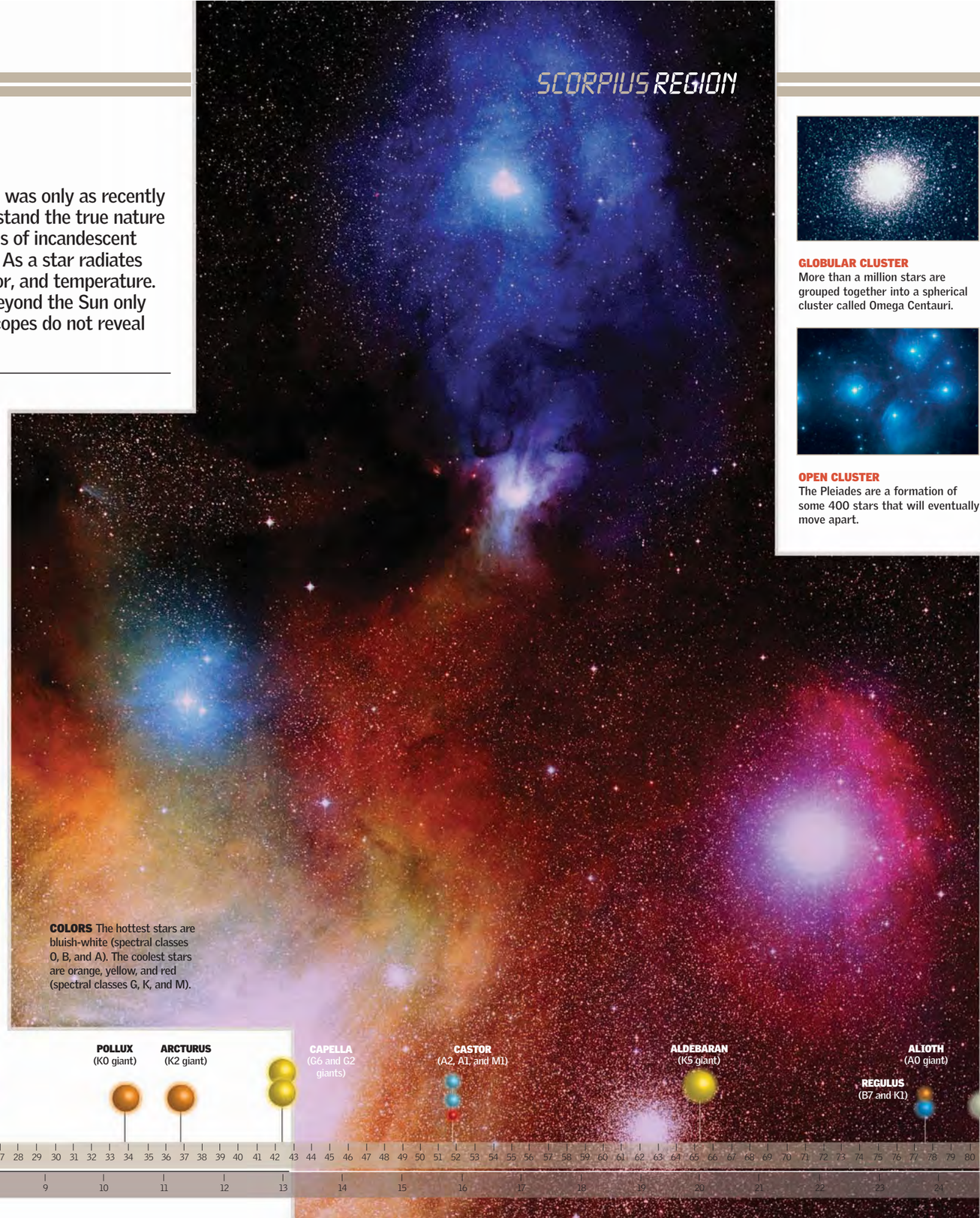
TYPE G 8,500-10,500° F (4,700-5,800° C)

TYPE K 6,000-8,500° F (3,300-4,700° C)

TYPE M 4,000-6,000° F (2,100-3,300° C)

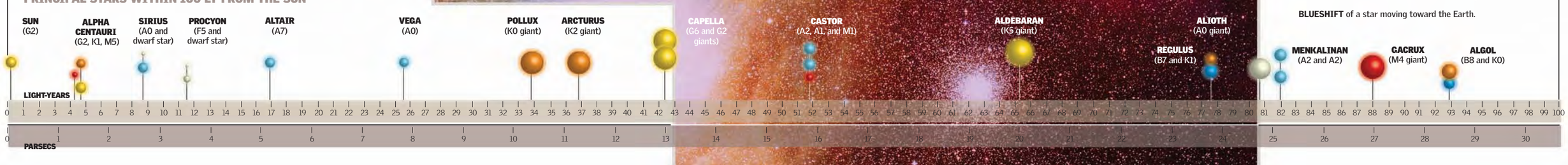
Light-years and Parsecs

In measuring the great distances between stars, both light-years (ly) and parsecs (pc) are used. A light-year is the distance that light travels in a year—5.9 trillion miles (10 trillion km). A light-year is a unit of distance, not time. A parsec is equivalent to the distance between the star and the Earth if the parallax angle is of one second arc. A pc is equal to 3.26 light-years, or 19 trillion miles (31 trillion km).



COLORS The hottest stars are bluish-white (spectral classes O, B, and A). The coolest stars are orange, yellow, and red (spectral classes G, K, and M).

PRINCIPAL STARS WITHIN 100 LY FROM THE SUN

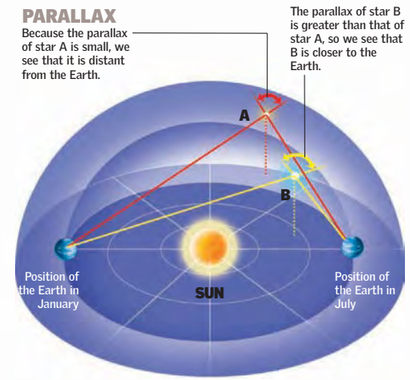


GLOBULAR CLUSTER
More than a million stars are grouped together into a spherical cluster called Omega Centauri.

OPEN CLUSTER
The Pleiades are a formation of some 400 stars that will eventually move apart.

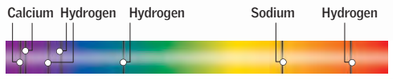
Measuring Distance

When the Earth orbits the Sun, the closest stars appear to move in front of a background of more distant stars. The angle described by the movement of a star in a six-month period of the Earth's rotation is called its parallax. The parallax of the most distant stars are too small to measure. The closer a star is to the Earth, the greater its parallax.



Spectral Analysis

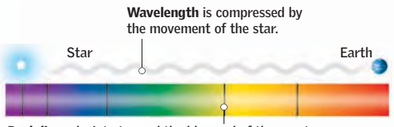
The electromagnetic waves that make up light have different wavelengths. When light from a hot object, such as a star, is split into its different wavelengths, a band of colors, or spectrum, is obtained. Patterns of dark lines typically appear in the spectrum of a star. These patterns can be studied to determine the elements that make up the star.



Wavelength longest on the red side

DOPPLER EFFECT

When a star moves toward or away from an observer, its wavelengths of light shift, a phenomenon called the Doppler effect. If the star is approaching the Earth, the dark lines in its spectrum experience a blueshift. If it moves away from the Earth, the lines experience a redshift.



Dark lines deviate toward the blue end of the spectrum.

BLUESHIFT of a star moving toward the Earth.

Stellar Evolution

Stars are born in nebulae, which are giant clouds of gas (mainly hydrogen) and dust that float in space. Stars can have a life span of millions, or even billions, of years. The biggest stars have the shortest lives, because they consume their nuclear fuel (hydrogen) at a very accelerated rate. Other stars, like the Sun, burn fuel at a slower rate and may live some 10 billion years. Many times, a star's size indicates its age. Smaller stars are the youngest, and bigger stars are approaching their end, either through cooling or by exploding as a supernova.

Massive star

More than 8 solar masses

1. PROTOSTAR
A protostar has a dense, gaseous core surrounded by a cloud of dust.

2. STAR
A star is finally born. It fuses hydrogen to form helium and lies along the main sequence.

3. RED SUPERGIANT
The star swells and heats up. Through nuclear reactions, a heavy core of iron is formed.

4. SUPERNOVA When the star can no longer fuse any more elements, its core collapses, causing a strong emission of energy.

5. BLACK HOLE If the star's initial mass is 20 solar masses or more, its nucleus is denser and it turns into a black hole, whose gravitational force is extremely strong.

5. NEUTRON STAR
If the star's initial mass is between eight and 20 solar masses, it ends up as a neutron star.

Nebula

A CLOUD OF GAS AND DUST collapses because of gravitational forces. In doing so it heats up and divides into smaller clouds. Each one of these clouds will form a protostar.

Small star

Less than 8 solar masses

1. PROTOSTAR
A protostar is formed by the separation of gas and dust. Gravitational effects cause its core to rotate.

2. STAR The star shines and slowly consumes its hydrogen. It begins to fuse helium as its size increases.

3. RED GIANT The star continues to expand, but its mass remains constant and its core heats up. When the star's helium is depleted, it fuses carbon and oxygen.

4. PLANETARY NEBULA When the star's fuel is depleted, its core condenses, and its outer layers detach, expelling gases in an expanding shell of gases.

5. WHITE DWARF
The star remains surrounded by gases and is dim.

6. BLACK DWARF
If a white dwarf fades out completely, it becomes a black dwarf.

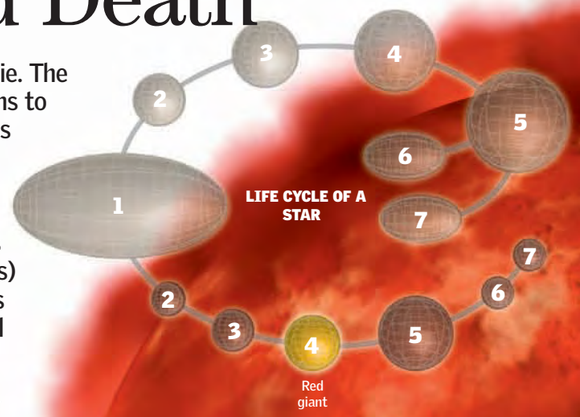
Life Cycle of a Star

The evolution of a star depends on its mass. The smallest ones, like the Sun, have relatively long and modest lives. Such a star begins to burn helium when its hydrogen is depleted. In this way, its external layers begin to swell until the star turns into a red giant. It ends its life as white dwarfs, eventually fading away completely, ejecting remaining outer layers, and forming a planetary nebula. A massive star, because of its higher density, can form elements heavier than helium from its nuclear reactions. In the final stage of its life, its core collapses and the star explodes. All that remains is a hyperdense remnant, a neutron star. The most massive stars end by forming black holes.

95% of stars end their lives as white dwarfs. Other (larger) stars explode as supernovae, illuminating galaxies for weeks, although their brightness is often obscured by the gases and dust.

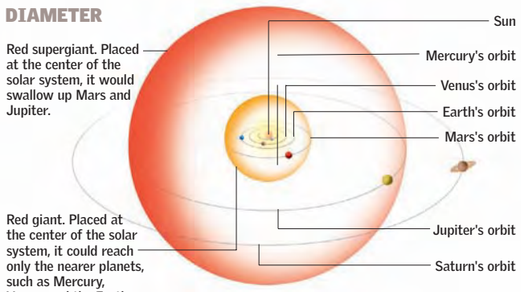
Red, Danger, and Death

When a star exhausts its hydrogen, it begins to die. The helium that now makes up the star's core begins to undergo nuclear reactions, and the star remains bright. When the star's helium is depleted, fusion of carbon and oxygen begins, which causes the star's core to contract. The star continues to live, though its surface layers begin to expand and cool as the star turns into a red giant. Stars similar to the Sun (solar-type stars) follow this process. After billions of years, they end up as white dwarfs. When they are fully extinguished, they will be black dwarfs, invisible in space. ●



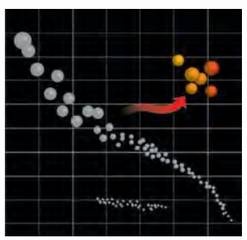
Red Giant

All stars go through a red-giant stage. Depending on a star's mass, it may collapse or it may simply die enveloped in gaseous layers. The core of a red giant is 10 times smaller than it was originally since it shrinks from a lack of hydrogen. A supergiant star (one with an initial mass greater than eight solar masses) lives a much shorter life. Because of the high density attained by its core, it eventually collapses in on itself and explodes.

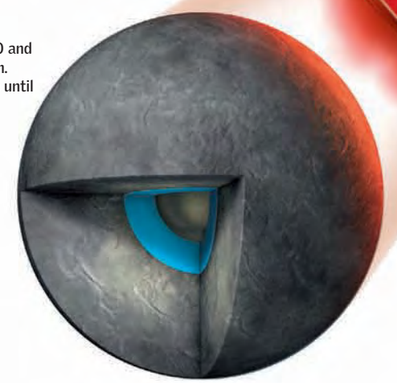


SPECTACULAR DIMENSIONS

On leaving the main sequence, the star enlarges to 200 times the size of the Sun. When the star begins to burn helium, its size decreases to between 10 and 100 times the size of the Sun. The star then remains stable until it becomes a white dwarf.



HERTZSPRUNG-RUSSELL
When the star exhausts its hydrogen, it leaves the main sequence and burns helium as a red giant (or a supergiant). The smallest stars take billions of years to leave the main sequences. The color of a red giant is caused by its relatively cool surface temperature of 3,600° F (2,000° C).



Convection Cells

Convection cells carry heat toward the surface of a star. The ascending currents of gas eventually reach the surface of the star, carrying with them a few elements that formed in the star's core.

Hot Spots

Hot spots appear when large jets of incandescent gas reach the star's surface. They can be detected on the surface of red giants.

Dust Grains

Dust grains condense in the star's outer atmosphere and later disperse in the form of stellar winds. The dust acquires a dark appearance and is swept into interstellar space, where new generations of stars will form. The outer layer of the star may extend across several light-years of interstellar space.

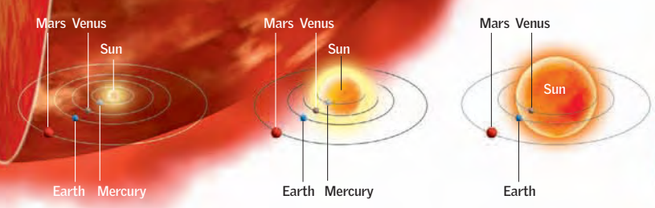
REGION OF THE CORE

1 HYDROGEN
Hydrogen continues undergoing nuclear fusion in the exterior of the core even when the inner core has run out of hydrogen.

2 HELIUM
Helium is produced by the fusion of hydrogen during the main sequence.

3 CARBON AND OXYGEN
Carbon and oxygen are produced by the fusion of helium within the core of the red giant.

4 TEMPERATURE
As the helium undergoes fusion, the temperature of the core reaches millions of degrees Fahrenheit (millions of degrees Celsius).



THE FUTURE OF THE SUN

Like any typical star, the Sun burns hydrogen during its main sequence. After taking approximately five billion years to exhaust its supply of hydrogen, it will begin its transformation into a red giant, doubling in brightness and expanding until it swallows Mercury. At its maximum size, it may even envelop the Earth. Once it has stabilized, it will continue as a red giant for two billion years and then become a white dwarf.

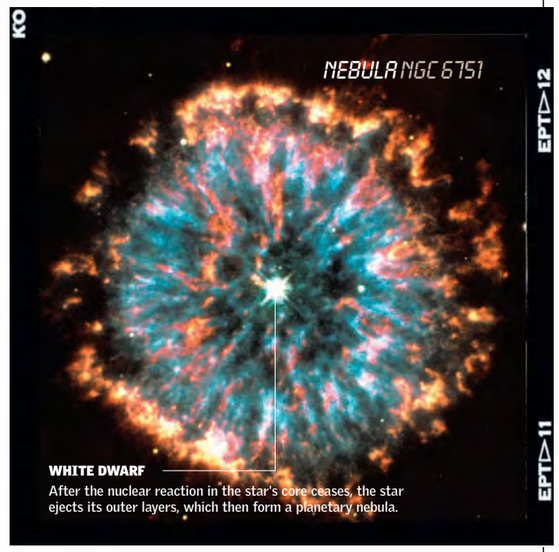
SUN

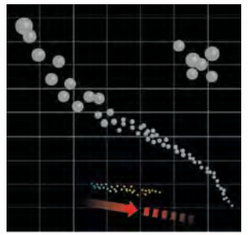
1%

The scale of the diameter of the Sun to the diameter of a typical red giant.

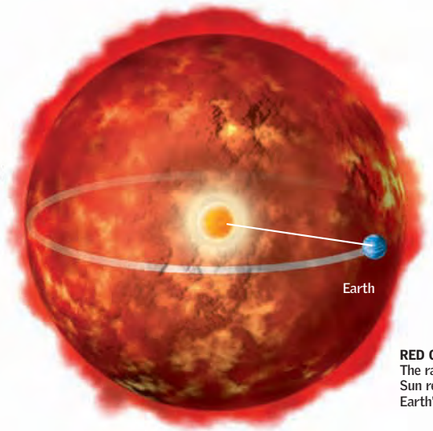
White Dwarf

After going through the red-giant stage, a solar-type star loses its outer layers, giving rise to a planetary nebula. In its center remains a white dwarf—a relatively small, very hot (360,000° F [200,000° C]), dense star. After cooling for millions of years, it shuts down completely and becomes a black dwarf.





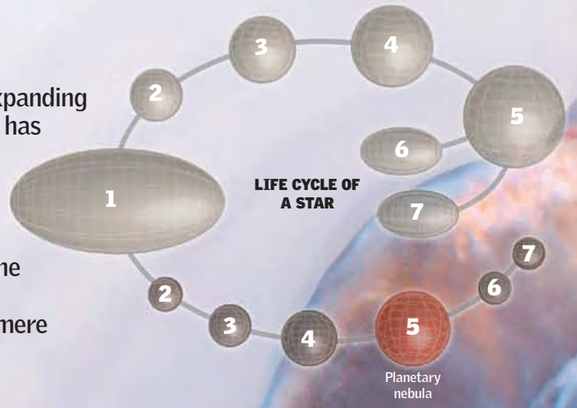
HERTZSPRUNG-RUSSELL
When a white dwarf leaves the red-giant stage, it occupies the lower-left corner of the H-R diagram. Its temperature may be double that of a typical red giant. A massive white dwarf can collapse in on itself and end its life as a neutron star.



RED GIANT
The radius of the Sun reaches the Earth's orbit.

Gas Shells

When a small star dies, all that remains is an expanding gas shell known as a planetary nebula, which has nothing to do with the planets. In general, planetary nebulae are symmetrical or spherical objects. Although it has not been possible to determine why they exist in such diversity, the reason may be related to the effects of the magnetic field of the dying central star. Viewed through a telescope, several nebulae can be seen to contain a central dwarf star, a mere remnant of its precursor star. ●



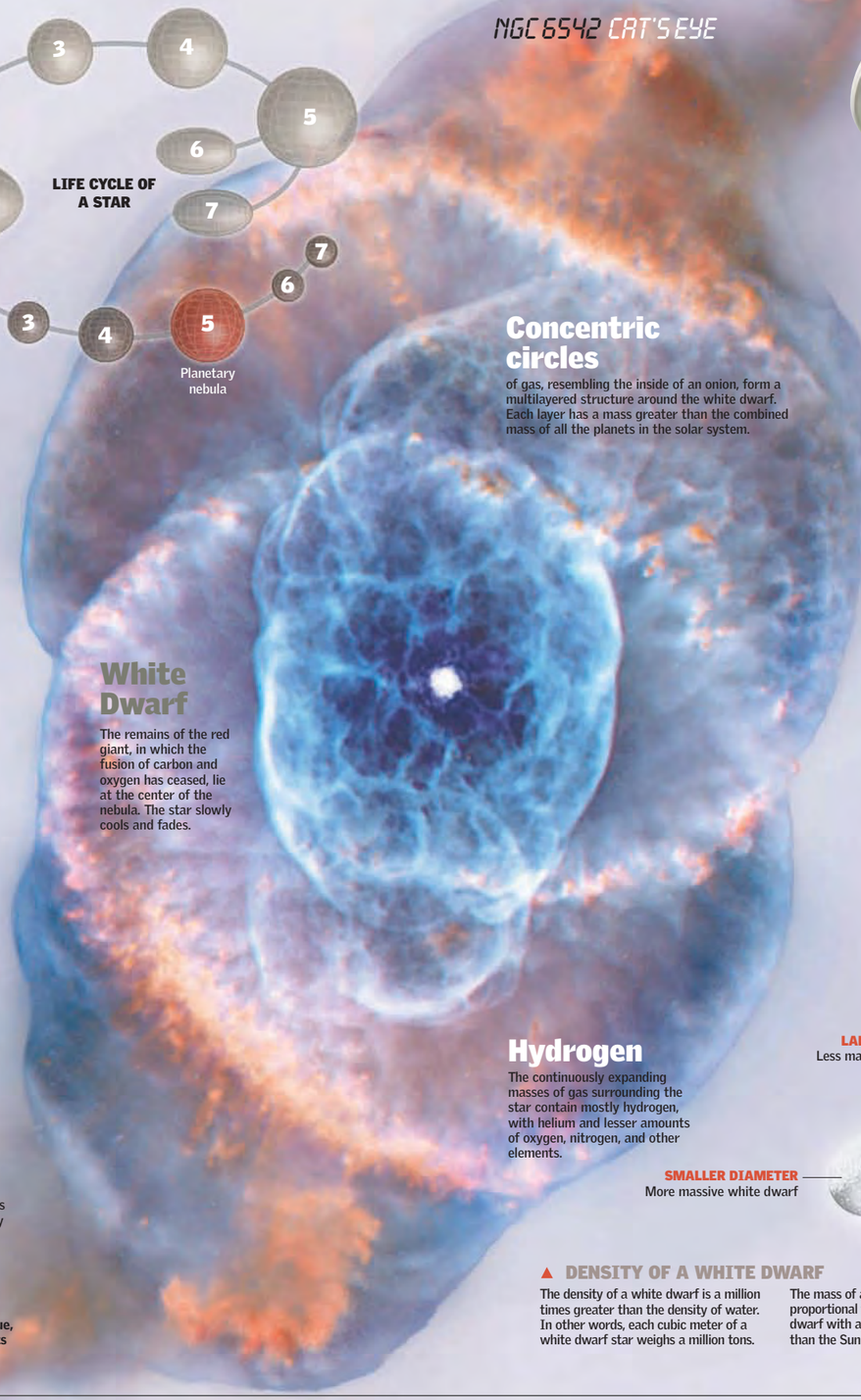
◄ M2-9
The Butterfly Nebula contains a star in addition to a white dwarf. Each orbits the other inside a gas disk that is 10 times larger than Pluto's orbit. The Butterfly Nebula is located 2,100 light-years from Earth.

TWICE THE TEMPERATURE OF THE SUN
is reached at the surface of a white dwarf, causing it to appear white even though its luminosity is a thousand times less than that of the Sun.

◄ IC 418
The Spirograph Nebula has a hot, luminous core that excites nearby atoms, causing them to glow. The Spirograph Nebula is about 0.1 light-year wide and is located 2,000 light-years from Earth.

CHANDRASEKHAR LIMIT
The astrophysicist Subrahmanyan Chandrasekhar, winner of the Nobel Prize for Physics in 1983, calculated the maximum mass a star could have so that it would not eventually collapse on itself. If a star's mass exceeds this limit, the star will eventually explode in a supernova.

1.44 SOLAR MASSES
is the limit Chandrasekhar obtained. In excess of this value, a dwarf star cannot support its own gravity and collapses.



3 tons
is the weight of a single tablespoon of a white dwarf. A white dwarf is very massive in spite of the fact that its diameter of 9,300 miles (or 15,000 km) is comparable to the Earth's.

NGC 7293 ►
The Helix is a planetary nebula that was created at the end of the life of a solar-type star. It is 650 light-years from the Earth and is located in the constellation Aquarius.

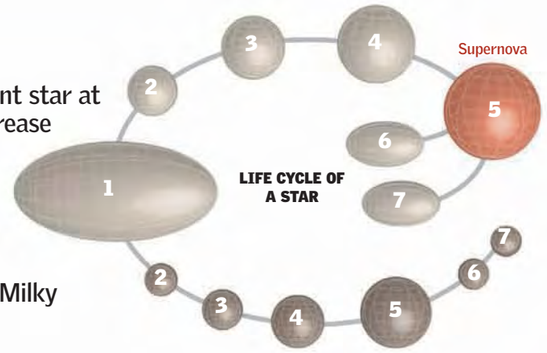
MYCN 18 ►
The two rings of colored gas form the silhouette of this hourglass-shaped nebula. The red in the photograph corresponds to nitrogen, and the green corresponds to hydrogen. This nebula is 8,000 light-years from the Earth.

▲ DENSITY OF A WHITE DWARF
The density of a white dwarf is a million times greater than the density of water. In other words, each cubic meter of a white dwarf star weighs a million tons.

The mass of a star is indirectly proportional to its diameter. A white dwarf with a diameter 100 times smaller than the Sun has a mass 70 times greater.

Supernovae

A supernova is an extraordinary explosion of a giant star at the end of its life, accompanied by a sudden increase in brightness and the release of a great amount of energy. In 10 seconds, a supernova releases 100 times more energy than the Sun will release in its entire life. After the explosion of the star that gives rise to a supernova, the gaseous remnant expands and shines for millions of years. It is estimated that, in our Milky Way galaxy, two supernovae occur per century. ●



◂FEBRUARY 22, 1987
This star is in its last moments of life. Because it is very massive, it will end its life in an explosion. The galaxy exhibits only its usual luminosity.

FEBRUARY 23, 1987 ▸
After the supernova explosion, increased brightness is observed in the region near the star.

BEFORE AND AFTER
The image at left shows a sector of the Large Magellanic Cloud, an irregular galaxy located 170,000 light-years from the Earth, depicted before the explosion of supernova 1987A. The image at right shows the supernova.

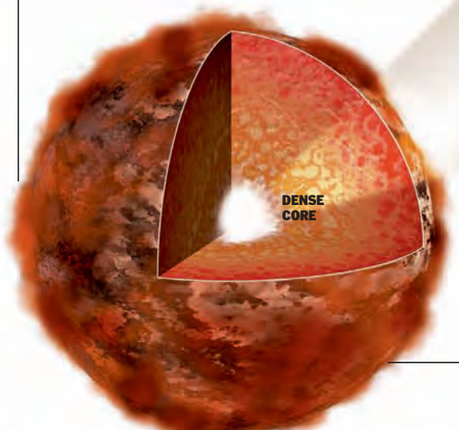
The Twilight of a Star

The explosion that marks the end of a supergiant's life occurs because the star's extremely heavy core has become incapable of supporting its own gravity any longer. In the absence of fusion in its interior, the star falls in upon itself, expelling its remaining gases, which will expand and shine for hundreds—or even thousands—of years. The explosion of the star injects new material into interstellar space and contributes heavy atoms that can give rise to new generations of stars.

Core

A star's core can be seen to be separated into distinct layers that correspond to the different elements created during nuclear fusion. The last element created before the star's collapse is iron.

FUSION
The nuclear reactions in a dying star occur at a faster rate than they do in a red giant.



Supergiant

The diameter of the star may increase to more than 1,000 times that of the Sun. Through nuclear fusion, the star can produce elements even heavier than carbon and oxygen.

Other Elements

When a star's iron core increases in density to 1.44 solar masses, the star can no longer support its own weight and it collapses upon itself. The resulting explosion causes the formation of elements that are heavier than iron, such as gold and uranium.

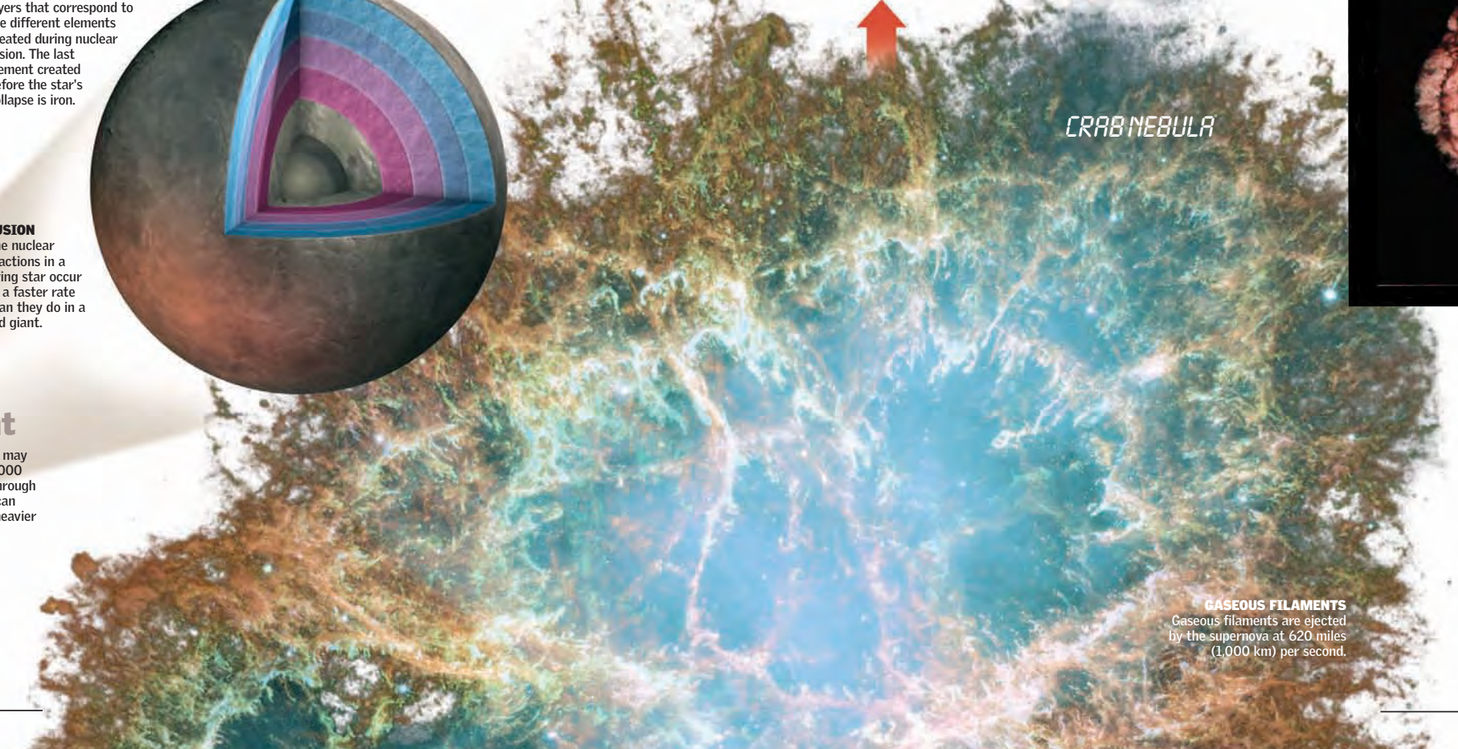
THE END
Either a neutron star or a black hole may form depending on the initial mass of the star that has died.

Explosion

The star's life ends in an immense explosion. During the weeks following the explosion, great quantities of energy are radiated that are sometimes greater than the energy emitted by the star's parent galaxy. A supernova may illuminate its galaxy for weeks.

SUPERMASSIVE
The mass of Eta Carinae is 100 times greater than that of the Sun. Astronomers believe that Eta Carinae is about to explode, but no one knows when.

GAS AND DUST
Gas and dust that have accumulated in the two visible lobes absorb the blue light and ultraviolet rays emitted from its center.



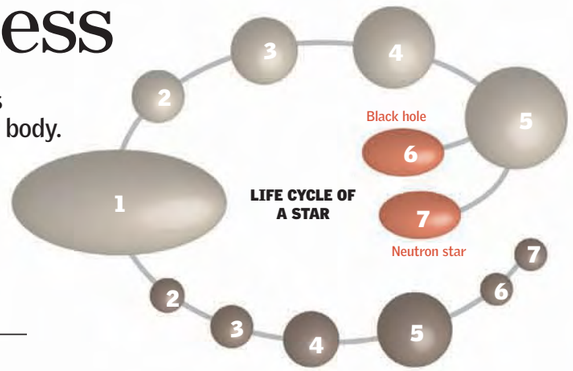
GASEOUS FILAMENTS
Gaseous filaments are ejected by the supernova at 620 miles (1,000 km) per second.

Stellar Remnant

When the star explodes as a supernova, it leaves as a legacy in space the heavy elements (such as carbon, oxygen, and iron) that were in the star's nucleus before its collapse. The Crab Nebula (M1) was created by a supernova seen in 1054 by Chinese astronomers. The Crab Nebula is located 6.5 light-years from Earth and has a diameter of six light-years. The star that gave rise to the Crab Nebula may have had an initial mass close to 10 solar masses. In 1969, a pulsar radiating X-rays and rotating 33 times per second was discovered at the center of the nebula, making the Crab Nebula a very powerful source of radiation.

The Final Darkness

The last stage in the evolution of a star's core is its transformation into a very dense, compact stellar body. Its particulars depend upon the amount of mass involved in its collapse. The largest stars become black holes, their density so great that their gravitational forces capture even light. The only way to detect these dead stars is by searching for the effects of their gravitation.

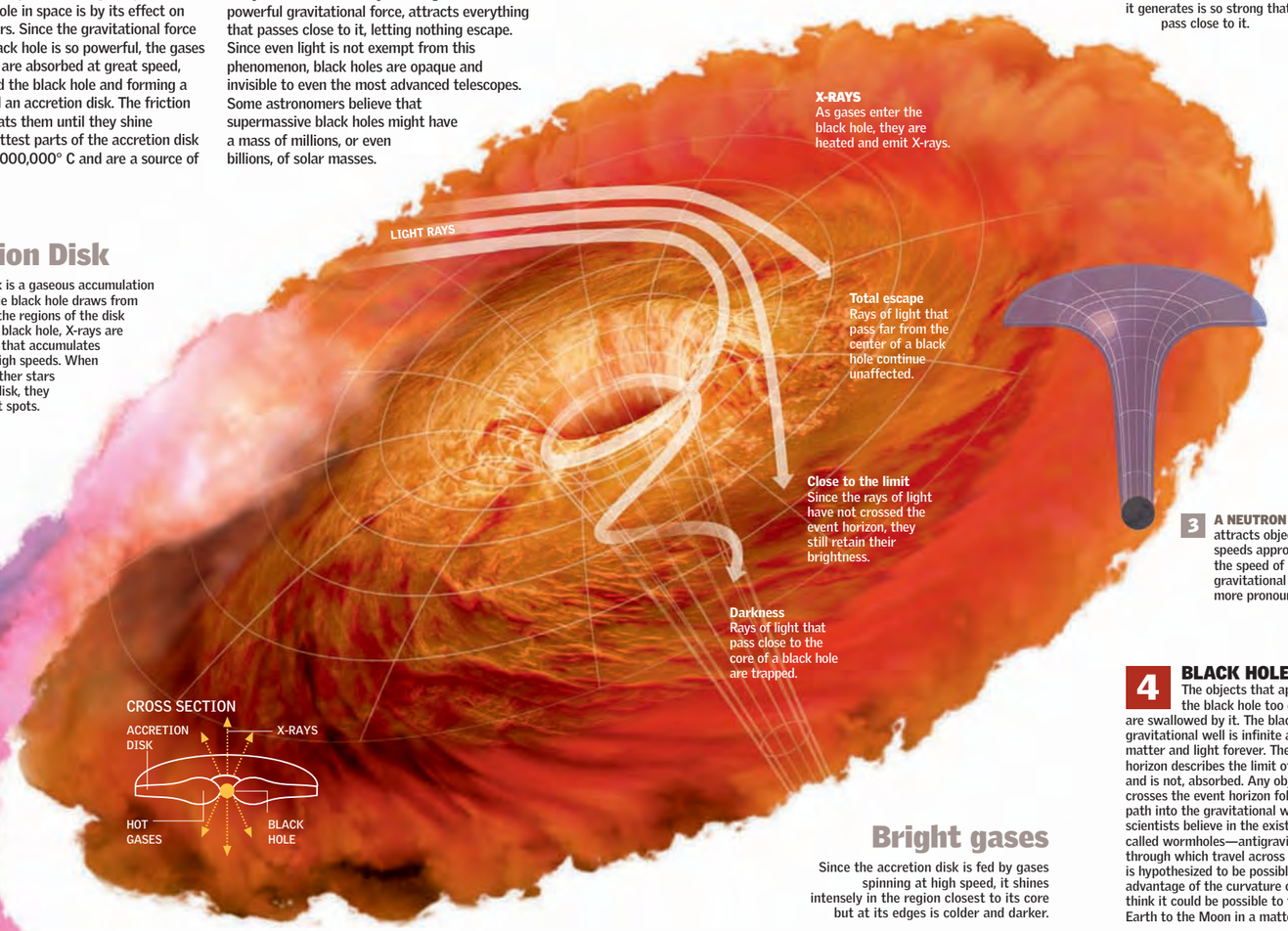


Discovery of Black Holes

The only way of detecting the presence of a black hole in space is by its effect on neighboring stars. Since the gravitational force exerted by a black hole is so powerful, the gases of nearby stars are absorbed at great speed, spiraling toward the black hole and forming a structure called an accretion disk. The friction of the gases heats them until they shine brightly. The hottest parts of the accretion disk may reach 100,000,000° C and are a source of X-rays. The black hole, by exerting such powerful gravitational force, attracts everything that passes close to it, letting nothing escape. Since even light is not exempt from this phenomenon, black holes are opaque and invisible to even the most advanced telescopes. Some astronomers believe that supermassive black holes might have a mass of millions, or even billions, of solar masses.

Accretion Disk

An accretion disk is a gaseous accumulation of matter that the black hole draws from nearby stars. In the regions of the disk very close to the black hole, X-rays are emitted. The gas that accumulates rotates at very high speeds. When the gases from other stars collide with the disk, they create bright, hot spots.



Bright gases

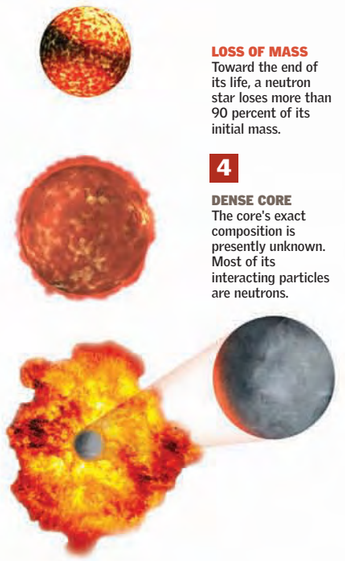
Since the accretion disk is fed by gases spinning at high speed, it shines intensely in the region closest to its core but at its edges is colder and darker.

Neutron Star

When a star's initial mass is between 10 and 20 solar masses, its final mass will be larger than the mass of the Sun. Despite losing great quantities of matter during nuclear reactions, the star finishes with a very dense core. Because of its intense magnetic and gravitational fields, a neutron star can end up as a pulsar. A pulsar is a rapidly spinning neutron star that gives off a beam of radio waves or other radiation. As the beam sweeps around the object, the radiation is observed in very regular pulses.

Strong Gravitational Attraction

The gravitational force of the black hole attracts gases from a neighboring star. This gas forms a large spiral that swirls faster and faster as it gets closer to the black hole. The gravitation field that it generates is so strong that it traps objects that pass close to it.



1 RED GIANT
A red giant leaves the main sequence. Its diameter is 100 times greater than the Sun's.

2 SUPERGIANT
A supergiant grows and rapidly fuses heavier chemical elements, forming carbon, oxygen, and finally iron.

3 EXPLOSION
The star's iron core collapses. Protons and electrons annihilate each other and form neutrons.

4 DENSE CORE
The core's exact composition is presently unknown. Most of its interacting particles are neutrons.

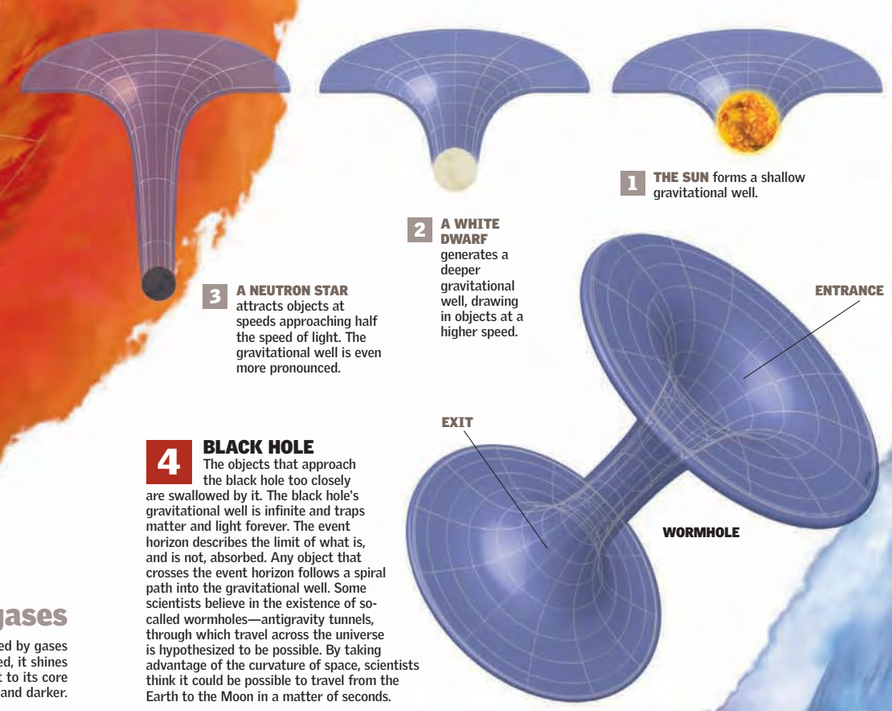
LOSS OF MASS
Toward the end of its life, a neutron star loses more than 90 percent of its initial mass.

1 billion

tons is what one tablespoon of a neutron star would weigh. Its small diameter causes the star to have a compact, dense core accompanied by intense gravitational effects.

CURVED SPACE

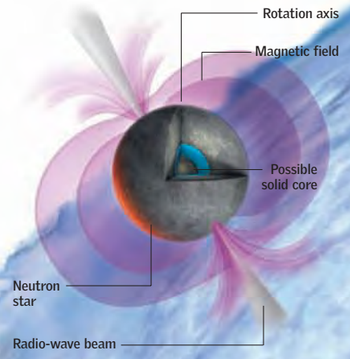
The theory of relativity suggests that gravity is not a force but a distortion of space. This distortion creates a gravitational well, the depth of which depends on the mass of the object. Objects are attracted to other objects through the curvature of space.



Pulsars

The first pulsar (a neutron star radiating radio waves) was discovered in 1967. Pulsars rotate approximately 30 times per second and have very intense magnetic fields. Pulsars emit radio waves from their two magnetic poles when they rotate. If a pulsar absorbs gas from a neighboring star, a hot spot that radiates X-rays is produced on the pulsar's surface.

STRUCTURE OF A PULSAR



Devouring gas from a supergiant

Located within a binary system, the pulsar can follow the same process as a black hole. The pulsar's gravitational force causes it to absorb the gas of smaller, neighboring stars, heating up the pulsar's surface and causing it to emit X-rays.

Anatomy of Galaxies

Galaxies are rotating groups of stars, gas, and dust. More than 200 years ago, philosopher Immanuel Kant postulated that nebulae were island-universes of distant stars. Even though astronomers now know that galaxies are held together by gravitational force, they have not been able to decipher what reasons might be behind galaxies' many shapes. The various types of galaxies range from ovals of old stars to spirals with arms of young stars and bright gases. The center of a galaxy has the greatest accumulation of stars. The Milky Way Galaxy is now known to be so big that rays of light, which travel at 186,000 miles (300,000 km) per second, take 100,000 years to cross from one end to the other.

MILKY WAY
Seen from its side, the Milky Way looks like a flattened disk, swollen at the center. Around the disk is a spherical region, called a halo, containing dark matter and globular clusters of stars. From June to September, the Milky Way is especially bright, something that would make it more visible viewed from above than from the side.

CLASSIFYING GALAXIES ACCORDING TO HUBBLE

ELLIPTICAL
These galaxies are elliptical in shape and have little dust and gas. Their masses fall within a wide range.

SPIRAL
In a spiral galaxy, a nucleus of old stars is surrounded by a flat disk of stars and two or more spiral arms.

IRREGULAR
Irregular galaxies have no defined shape and cannot be classified. They contain a large amount of gases and dust clouds.

SUBCLASSIFICATIONS

SUBCLASSIFICATIONS
Galaxies are subdivided into different categories according to their tendency toward round shape (in the case of elliptical galaxies), as well as by the presence of an axis and the length of their arms (in the case of spiral and barred spiral galaxies). An E0 galaxy is elliptical but almost circular, and an E7 galaxy is a flattened oval. An Sa galaxy has a large central axis and coiled arms, and an Sc galaxy has a thinner axis and more extended arms.

Galactic Clusters

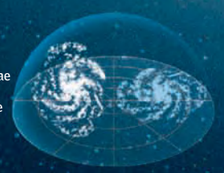
Galaxies are objects that tend to form groups or clusters. Acting in response to gravitational force, they can form clusters of galaxies of anywhere from two to thousands of galaxies. These clusters have various shapes and are thought to expand when they join together. The Hercules cluster, shown here, was discovered by Edmond Halley in 1714 and is located approximately 25,100 light-years from Earth. Each dot represents a galaxy that includes billions of stars.

Star Cities

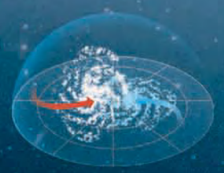
The first galaxies formed 100 million years after the big bang. Billions of these great conglomerates of stars can be found throughout space. The two most important discoveries concerning galaxies are attributed to the astronomer Edwin Hubble. In 1926, he pointed out that the spots, or patches, of light visible in the night sky were actually distant galaxies. Hubble's discovery put an end to the view held by astronomers at the time that the Milky Way constituted the universe. In 1929, as a result of various observations of the spectrum of light radiated by the stars in the galaxies, Hubble noted that the light from the galaxies showed a redshift (Doppler effect). This effect indicated that the galaxies were moving away from the Milky Way Galaxy. Hubble concluded that the universe is expanding. But the expansion of the universe does not imply that galaxies are growing in numbers. On the contrary, galaxies can collide and merge. When two galaxies collide, they can distort each other in various ways. Over time, there are fewer and fewer galaxies. Some galaxies exhibit very peculiar shapes. The Sombrero Galaxy, shown in the center of the page, has a bright white core surrounded by thin spiral arms.

COLLISION
300 million light-years from the Earth, these two colliding galaxies form a pair. Together they are called "The Mice" for the large tail of stars emanating from each galaxy. With time, these galaxies will fuse into a single, larger one. It is believed that in the future the universe will consist of a few giant stars.

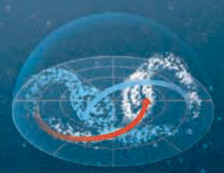
1
1.2 BILLION YEARS
ago, the Antennae (NGC 4038 and NGC 4039) were two separate spiral galaxies.



2
300 MILLION YEARS
later, the galaxies collided at great speed.



3
300 MILLION YEARS
go by until the collision takes place and the shapes of the galaxies are distorted.



4
300 MILLION YEARS
later, the stars in the spiral arms are expelled from both galaxies.

5
NOW
two jets of expelled stars stretch far from the original galaxies.

Active Galaxies

A small number of galaxies differ from the rest by emitting high amounts of energy. The energy emission might be caused by the presence of black holes in its core that were formed through the gravitational collapse accompanying the death of supermassive stars. During their first billion years, the galaxies might have accumulated surrounding gaseous disks with their corresponding emissions of radiation. It is possible that the cores of the first galaxies are the quasars that are now observed at very great distances. ●

Energetic Activity

Astronomers believe that active galaxies are a direct legacy from the beginning of the universe. After the big bang, these galaxies would have retained very energetic levels of radiation. Quasars, the brightest and most ancient objects in the universe, make up the core of this type of galaxy. In some cases, they emit X-rays or radio waves. The existence of this high-energy activity helps support the theory that galaxies could be born from a supermassive black hole with a quasar that became inactive as stars formed and it was left without gas to feed it. This process of formation might be common to many galaxies. Today quasars represent the limit of what it is possible to see, even with specialized telescopes. Quasars are small, dense, and bright.

GAS
As two jets are expelled from the core, radio waves are emitted. If the waves collide with clouds of intergalactic gas, they swell and form gigantic clouds that can emit radio waves or X-rays.

CENTRAL RING
The core of an active galaxy is obscured by a ring of dust and gas that is dark on the outside and bright within. It is a powerful source of energy.

CLASSIFICATION
The classification of an active galaxy depends upon its distance from Earth and the perspective from which it is seen. Quasars, radio galaxies, and blazars are members of the same family of objects and differ only in the way they are perceived.

QUASARS The most powerful objects in the universe, quasars are so distant from Earth that they appear to us as diffuse stars. They are the bright cores of remote galaxies.

RADIO GALAXIES Radio galaxies are the largest objects in the universe. Jets of gases come out from their centers that extend thousands of light-years. The cores of radio galaxies cannot be seen.

BLAZARS Blazars may be active galaxies with jets of gas that are aimed directly toward Earth. The brightness of a blazar varies from day to day.

INCREASING GRAVITY

1 Dark clouds of gas and dust on the outer edge of a black hole are gradually swallowed up.

2 As the gases move inward, their temperature increases.

3 The strong gravitational force of the disk attracts and destroys stars.

4 The center of the black hole radiates charged particles.

GASEOUS CLOUDS
Gaseous clouds appeared from the gravitational collapse of immense masses of gas during the early stages of the universe. Later, in the clouds' interior, stars began to form.

Galaxy Formation

A theory of galaxy formation associated with active galaxies holds that many galaxies, possibly including the Milky Way, were formed from the gradual calming of a quasar at their core. As the surrounding gases consolidated in the formation of stars, the quasars, having no more gases to absorb, lost their energetic fury and became inactive. According to this theory, there is a natural progression from quasars to active galaxies to the common galaxies of today. In 1994, astronomers studying the center of the Milky Way discovered a region that may contain a black hole and could be left over from early galactic activity.

1

The Force of Gravity

Gravitational force begins to unite vast quantities of hot, gaseous clouds. The clouds attract one another and collide, forming stars. A large amount of gas accumulates at the center of the galaxy, intensifying gravitational forces until a massive black hole comes into being in the galaxy's core.

2

The Quasar in the Core

The quasar in the core ejects two jets of particles that reach speeds approaching the speed of light. The quasar stage is thought to have been the most violent stage in the formation of galaxies. The gases and stars arising from the jets are introduced as spirals into the black hole, forming a type of accretion disk known as a quasar.

3

Black Hole

A black hole swallows the gas that begins to surround it. A hot, gaseous spiral forms, emitting high-speed jets. The magnetic field pours charged particles into the region around the black hole, and the exterior of the disk absorbs interstellar gas.

ACCRETION DISK
Formed by interstellar gas and star remnants, the accretion disk can radiate X-rays because of the extreme temperature of its center.

PARTICLES
ejected from the black hole have intense magnetic fields. The jets of particles travel at speeds approaching the speed of light when they leave the core.

100
MILLION DEGREES
Celsius is the temperature that the core of a black hole can reach.

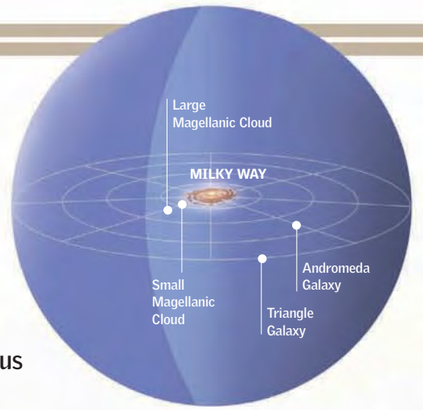
4

Stable Galaxy

Nine billion years after its formation, with a supermassive black hole at its core, the galaxy drastically slows its energetic activity, forming a low-energy core. The stabilization of the galaxy allowed the formation of stars and other heavenly bodies.

Stellar Metropolis

For a long time, our galaxy (called the Milky Way because of its resemblance to a stream of milk in the night sky) was a true enigma. It was Galileo Galilei who, in 1610, first pointed a telescope at the Milky Way and saw that the weak whitish strip was composed of thousands and thousands of stars that appeared to almost touch each other. Little by little, astronomers began to realize that all these stars, like our own Sun, were part of the enormous ensemble—the galaxy that is our stellar metropolis. ●

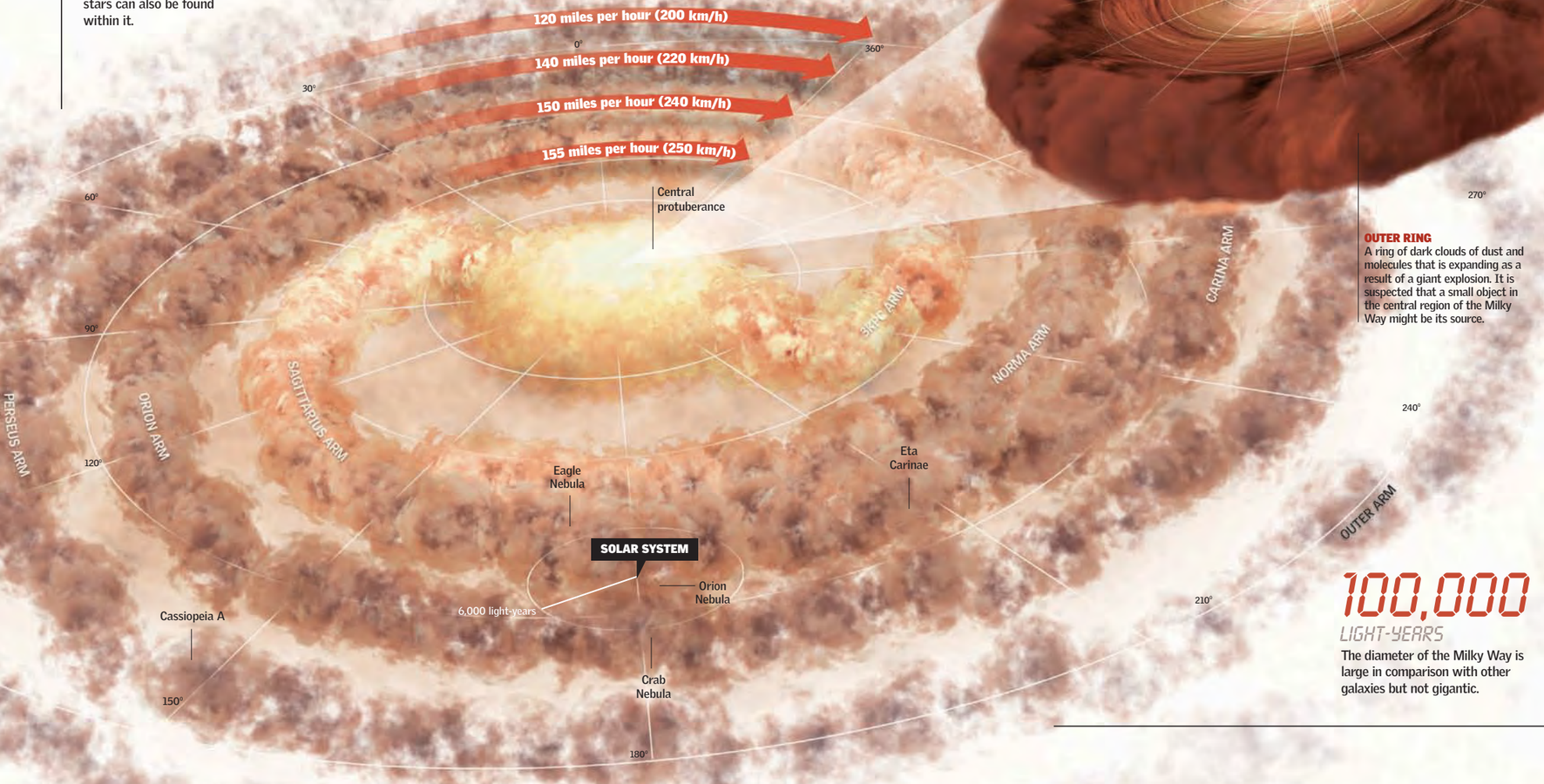


Structure of the Milky Way

The Milky Way, containing more than 100 billion stars, has two spiral arms rotating around its core. The Sagittarius arm, located between the Orion arm and the center of the Milky Way, holds one of the most luminous stars in the galaxy, Eta Carinae. The Perseus arm, the main outer arm of the Milky Way, contains young stars and nebulae. The Orion arm, extending between Perseus and Sagittarius, houses the solar system within its inner border. The Orion arm of the Milky Way is a veritable star factory, where gaseous interstellar material can give birth to billions of stars. Remnants of stars can also be found within it.

ROTATION

The speeds of the rotation of the various parts of the Milky Way vary according to those parts' distances from the core of the galaxy. The greatest number of stars is concentrated in the region between the Milky Way's core and its border. Here the speed of rotation is much greater because of the attraction that the objects in this region feel from the billions of stars within it.



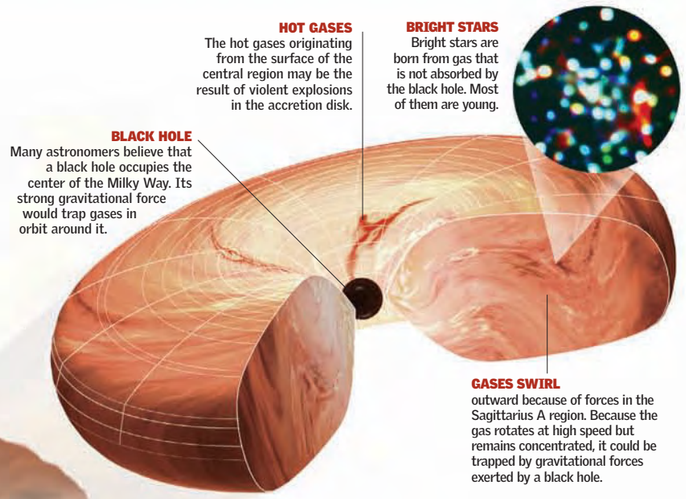
Central Region

Because the Milky Way is full of clouds of dust and rock particles, its center cannot be seen from outside the galaxy. The Milky Way's center can be seen only through telescopes that record infrared light, radio waves, or X-rays, which can pass through the material that blocks visible light. The central axis of the Milky Way contains ancient stars, some 14 billion years old, and exhibits intense activity within its interior, where two clouds of hot gas have been found: Sagittarius A and B. In the central region, but outside the core, a giant dark cloud contains 70 different types of molecules. These gas clouds are associated with violent activity in the center of our galaxy and contain the heart of the Milky Way within their depths. In general, the stars in this region are cold and range in color from red to orange.

SAGITTARIUS B2
The largest dark cloud in the central region of the Milky Way, Sagittarius B2 contains enough alcohol to cover the entire Earth.

MAGNETISM
The center of the Milky Way is surrounded by strong magnetic fields, perhaps from a rotating black hole.

OUTER RING
A ring of dark clouds of dust and molecules that is expanding as a result of a giant explosion. It is suspected that a small object in the central region of the Milky Way might be its source.



The Exact Center

The core of the Milky Way galaxy is marked by very intense radio-wave activity that might be produced by an accretion disk made up of incandescent gas surrounding a massive black hole. The region of Sagittarius A, discovered in 1994, is a gas ring that rotates at very high speed, swirling within several light-years of the center of the galaxy. The speed of its rotation is an indication of the powerful gravitational force exerted from the center of the Milky Way, a force stronger than would be produced by the stars located in the region. The hot, blue stars that shine in the center of the Milky Way may have been born from gas not yet absorbed by the black hole.

A Diverse Galaxy

The brightest portion of the Milky Way that appears in photographs taken with optical lenses (using visible light) is in the constellation Sagittarius, which appears to lie in the direction of the center of the Milky Way. The bright band in the nighttime sky is made up of stars so numerous that it is almost impossible to count them. In some cases, stars are obscured by dense dust clouds that make some regions of the Milky Way seem truly dark. The objects that can be found in the Milky Way are not all of one type. Some, such as those known as the halo population, are old and are distributed within a sphere around the galaxy. Other objects form a more flattened structure called the disk population. In the spiral arm population, we find the youngest objects in the Milky Way. In these arms, gas and interstellar dust abound.

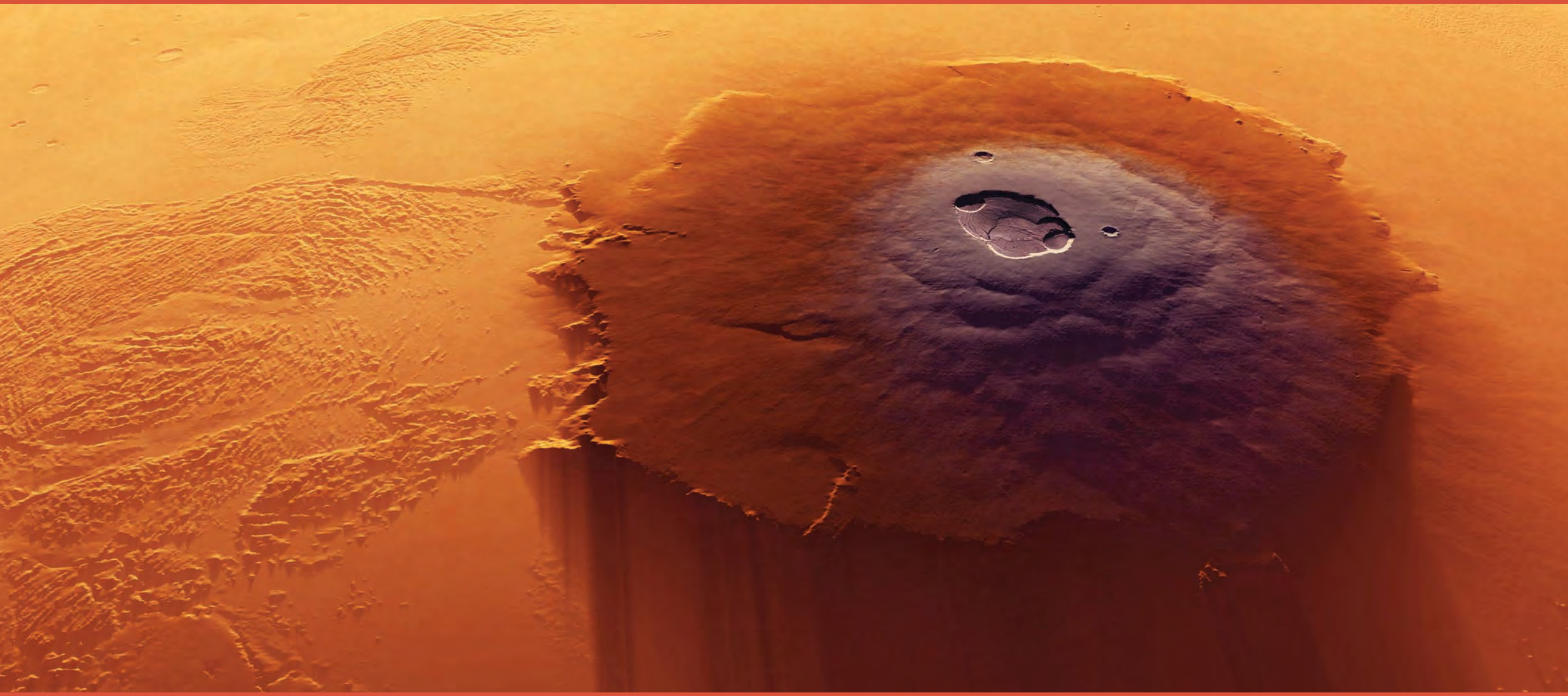
100,000
LIGHT-YEARS
The diameter of the Milky Way is large in comparison with other galaxies but not gigantic.

THE MILKY WAY IN VISIBLE LIGHT

The Solar System

OLYMPUS MONS, ON MARS
Olympus Mons is the largest volcano of the solar system. It is about two-and-a-half times as high as Mount Everest.

ATTRACTED BY A STAR 40-41
A VERY WARM HEART 42-43
MERCURY, AN INFERNO 44-45
VENUS, OUR NEIGHBOR 46-47
RED AND FASCINATING 48-49
JUPITER, GAS GIANT 50-51
THE LORD OF THE RINGS 52-53
URANUS WITHOUT SECRETS 54-55
NEPTUNE: DEEP BLUE 56-57
PLUTO: NOW A DWARF 58-59
DISTANT WORLDS 60-61
CONSTRUCTION DEBRIS: ASTEROIDS AND METEORITES 62-63
THOSE WITH A TAIL 64-65



Among the millions and millions of stars that form the Milky Way galaxy, there is a medium-sized one located in one of the galaxy's arms—the Sun. To ancient peoples, the Sun was a god; to us, it is the central source of energy that generates heat, helping life exist. This star, together with the planets and other bodies that spin in orbits around it, make up the solar system, which formed about 4.6 billion years ago. The planets that rotate around it do not produce their own light. Instead, they reflect sunlight. After the Earth, Mars is the most explored planet. Here we see a photo of Olympus Mons, the largest volcano in the entire solar system. It is almost two-and-a-half times as high as the tallest peak on the Earth, Mount Everest.

Attracted by a Star

Planets and their satellites, asteroids and other rocky objects, and an incalculable number of cometlike objects, some more than 1 trillion miles (1.6 trillion km) from the Sun, make up the solar system. In the 17th century, astronomer Johannes Kepler proposed a model to interpret the dynamic properties of the bodies of the solar system. According to this interpretation, the planets complete elliptical trajectories, called orbits, around the Sun. In every case, the movement is produced by the influence of the gravitational field of the Sun. Today, as part of a rapidly developing field of astronomy, it is known that planet or planetlike bodies also orbit other stars.

Outer Planets

Planets located outside the asteroid belt. They are enormous gas spheres with small solid cores. They have very low temperatures because of their great distance from the Sun. The presence of ring systems is exclusive to these planets. The greatest of them is Jupiter: 1,300 Earths could fit inside of it. Its mass is 2.5 times as great as that of the rest of the planets combined.

NEPTUNE

DIAMETER **30,775 MILES (49,528 KM)**
MOONS **13**

Triton Proteus Nereid

URANUS

DIAMETER **31,763 MILES (51,118 KM)**
MOONS **27**

Titania Oberon Umbriel Ariel Miranda Puck

SATURN

DIAMETER **74,898 MILES (120,536 KM)**
MOONS **50+**

Titan Rhea Iapetus Tethys

JUPITER

DIAMETER **88,846 MILES (142,984 KM)**
MOONS **60+**

Ganymede Callisto Io Europa

Asteroid Belt

The border between the outer and inner planets is marked by millions of rocky fragments of various sizes that form a band called the asteroid belt. Their orbits are influenced by the gravitational pull exerted on them by the giant planet Jupiter. This effect also keeps them from merging and forming a planet.

Inner Planets

Planets located inside the asteroid belt. They are solid bodies in which internal geologic phenomena, such as volcanism, which can modify their surfaces, are produced. Almost all of them have an appreciable atmosphere of some degree of thickness, according to individual circumstances, which plays a key role in the surface temperatures of each planet.

Phobos Deimos

MARS

DIAMETER **4,217 MILES (6,786 KM)**
MOONS **2**

MOON

EARTH

DIAMETER **7,926 MILES (12,756 KM)**
MOONS **1**

VENUS

DIAMETER **7,520 MILES (12,103 KM)**
MOONS **0**

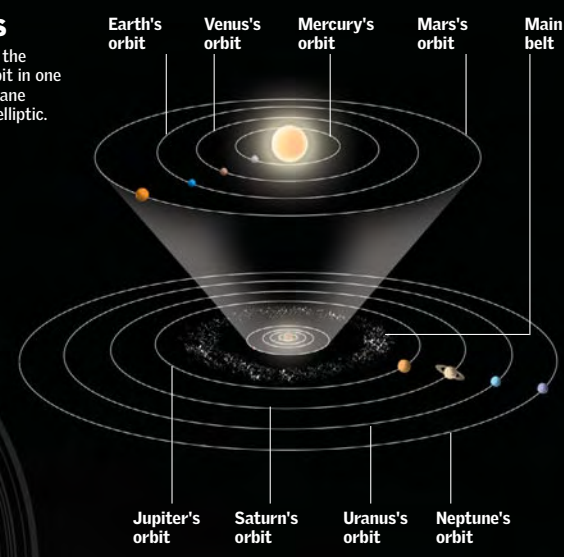
MERCURY

DIAMETER **3,031 MILES (4,878 KM)**
MOONS **0**

S U N

ORBITS

In general, the planets orbit in one common plane called the elliptic.



The rotation of most planets around their own axes is in counterclockwise direction. Venus and Uranus, however, revolve clockwise.

BUILDING PLANETS

Early ideas suggested that the planets formed gradually, beginning with the binding of hot dust particles. Today scientists suggest that the planets originated from the collision and melding of larger-sized bodies called planetesimals.

1

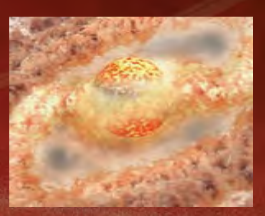
ORIGIN
Remains from the formation of the Sun created a disk of gas and dust around it, from which the planetesimals formed.

2

COLLISION
Through collisions among themselves, planetesimals of different sizes joined together to become more massive objects.

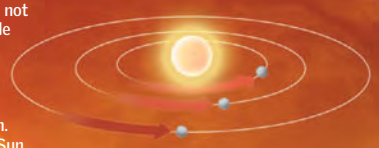
3

HEAT
The collisions produced a large amount of heat that accumulated in the interior of the planets, according to their distance from the Sun.



SOLAR GRAVITY

The gravitational pull of the Sun upon the planets not only keeps them inside the solar system but also influences the speed with which they revolve in their orbits around the Sun. Those closest to the Sun revolve in their orbits much faster than those farther from it.



A Very Warm Heart

The Sun at the center of the solar system is a source of light and heat. This energy is produced by the fusion of atomic hydrogen nuclei, which generate helium nuclei. The energy that emanates from the Sun travels through space and initially encounters the bodies that populate the solar system. The Sun shines thanks to thermonuclear fusion, and it will continue to shine until its supply of hydrogen runs out in about six or seven billion years.

Very Gassy

The Sun is a giant ball of gases with very high density and temperature. Its main components are hydrogen (90%) and helium (9%). The balance of its mass is made up of trace elements, such as carbon, nitrogen, and oxygen, among others. Because of the conditions of extreme temperature and pressure on the Sun, these elements are in a plasma state.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from Earth	93 million miles (150 million km)
Equatorial diameter	864,000 miles (1,391,000 km)
Orbital speed	7,456 miles per second (12,000 km/s)
Mass*	332,900
Gravity*	28
Density	0.81 ounce per cubic inch (1.4 g per cu cm)
Average temperature	9,932° F (5,500° C)
Atmosphere	Dense
Moons	None

*In both cases, Earth = 1

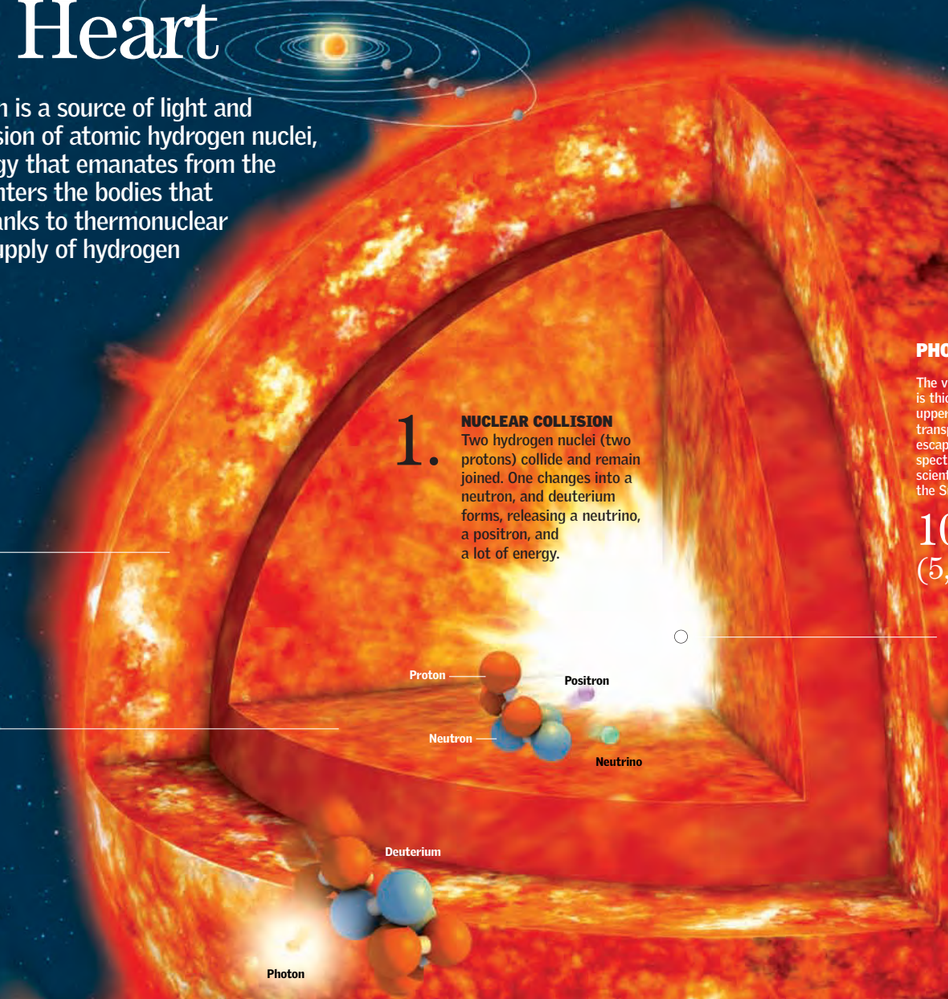
CONVECTIVE ZONE
extends from the base of the photosphere down to a depth of 15 percent of the solar radius. Here energy is transported up toward the surface by gas currents (through convection).

RADIATIVE ZONE
This portion of the Sun is traversed by particles coming from the core. A proton can take a million years to cross this zone.

14,400,000° F
(8,000,000° C)

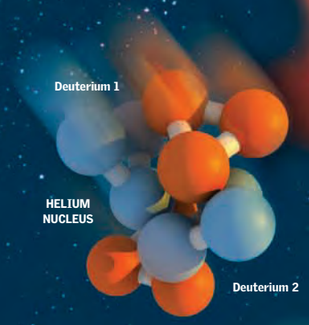
NUCLEAR FUSION OF HYDROGEN

The extraordinary temperature of the nuclear core helps the hydrogen nuclei join. Under conditions of lower energy, they repel each other, but the conditions at the center of the Sun can overcome the repulsive forces, and nuclear fusion occurs. For every four hydrogen nuclei, a series of nuclear reactions produce one helium nucleus.

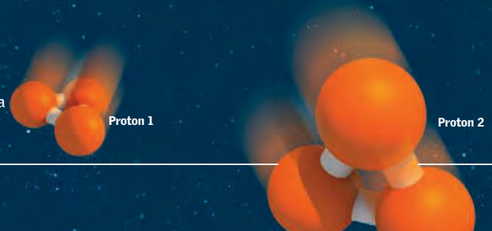


1. NUCLEAR COLLISION
Two hydrogen nuclei (two protons) collide and remain joined. One changes into a neutron, and deuterium forms, releasing a neutrino, a positron, and a lot of energy.

2. PHOTONS
The deuterium formed collides with a proton. This collision releases one photon and gamma rays. The high-energy photon needs 30,000 years to reach the photosphere.

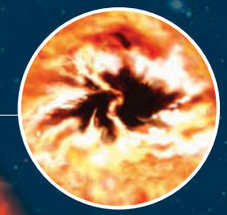


3. HELIUM NUCLEI
The group of two protons and a neutron collides with another such group. A helium nucleus forms, and a pair of protons is released.



Surface and Atmosphere

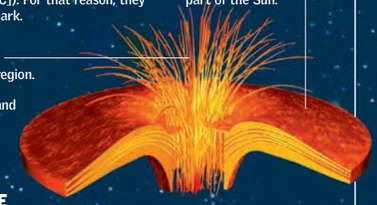
The visible portion of the Sun is a sphere of light, or photosphere, made of boiling gases emanating from the solar core. The gas flares form plasma, which passes through this layer. Later the gas flares enter a vast gas layer called the solar atmosphere. The density of this layer decreases toward its outermost region. Above the photosphere lies the solar atmosphere—the chromosphere and the corona. The energy generated at the core moves through the surface of the photosphere and solar atmosphere for thousands of years in search of an exit into space.



SUNSPOTS
are regions of gases that are generally colder (7,232° F [4,000° C]) than the photosphere (10,112° F [5,600° C]). For that reason, they appear dark.

PENUMBRA
Peripheral region. It is the hottest and brightest part of the Sun.

UMBRA
Central region. It is the coldest and darkest part.



PHOTOSPHERE
The visible surface of the Sun, a boiling tide, is thick with gases in a plasma state. In its uppermost layer, its density decreases and its transparency increases, and the solar radiation escapes from the Sun as light. The spectrographic study of this layer has allowed scientists to confirm that the main components of the Sun are hydrogen and helium.

10,112° F
(5,600° C)

CHROMOSPHERE
Above the photosphere, and of less density, lies the chromosphere, a layer 3,110 miles (5,000 km) thick. Its temperature ranges from 8,100° F (4,500° C) to 900,000° F (500,000° C) with increasing altitude. The temperature of the corona can reach 1,800,000° F (1,000,000° C).

900,000° F
(500,000° C)
MAXIMUM TEMPERATURE OF THE CHROMOSPHERE

CORE
The core occupies only 2 percent of the total volume of the Sun, but in it is concentrated about half the total mass of the Sun. The great pressures and temperatures in the core produce thermonuclear fusion.

27,000,000° F
(15,000,000° C)

SPICULES
Vertical jets of gas that spew from the chromosphere, usually reaching 6,200 miles (10,000 km) in height. They originate in upper convection cells and can rise as high as the corona.

MACROSPICULES
This type of vertical eruption is similar to a spicule, but it usually reaches up to 25,000 miles (40,000 km) in height.

CORONA
Located above the chromosphere, it extends millions of miles into space and reaches temperatures nearing 1,800,000° F (1,000,000° C). It has some holes, or low-density regions, through which gases flow into the solar wind.

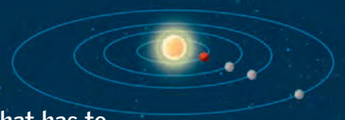
1,800,000° F
(1,000,000° C)
THE TEMPERATURE IN THE CORONA

SOLAR WIND
Consists of a flux of ions emitted by the solar atmosphere. The composition is similar to that of the corona. The Sun loses approximately 1,800 pounds (800 kg) of matter per second in the form of solar wind.

SOLAR PROMINENCES
Clouds and layers of gas from the chromosphere travel thousands of miles until they reach the corona, where the influence of magnetic fields causes them to take on the shape of an arc or wave.

SOLAR FLARES
These eruptions come out of the solar atmosphere and can interfere with radio communications on Earth.

Mercury, an Inferno



Mercury is the planet nearest to the Sun and is therefore the one that has to withstand the harshest of the Sun's effects. Due to its proximity to the Sun, Mercury moves at great speed in its solar orbit, completing an orbit every 88 days. It has almost no atmosphere, and its surface is dry and rugged, covered with craters caused by the impact of numerous meteorites; this makes it resemble the Moon. Numerous faults, formed during the cooling of the planet when it was young, are also visible on the surface. Constantly baked by its neighbor, the Sun, Mercury has an average surface temperature of 333° F (167° C).

A Scar-Covered Surface

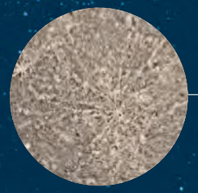
The surface of Mercury is very similar to that of the Moon. It is possible to find craters of varying sizes. The largest one has a diameter of some 810 miles (1,300 km). There are also hills and valleys. In 1991, radio telescopes were able to detect possible evidence of the presence of frozen water in Mercury's polar regions, information that Mariner 10 had been unable to gather. Mariner 10, the only mission sent to Mercury, flew by the planet three times between 1974 and 1975. The polar ice was found at the bottom of very deep craters, which limit the ice's exposure to the Sun's rays. The spacecraft Messenger, launched in 2004, is scheduled to orbit the planet Mercury in 2011 and is expected to provide new information about Mercury's surface and magnetic field.

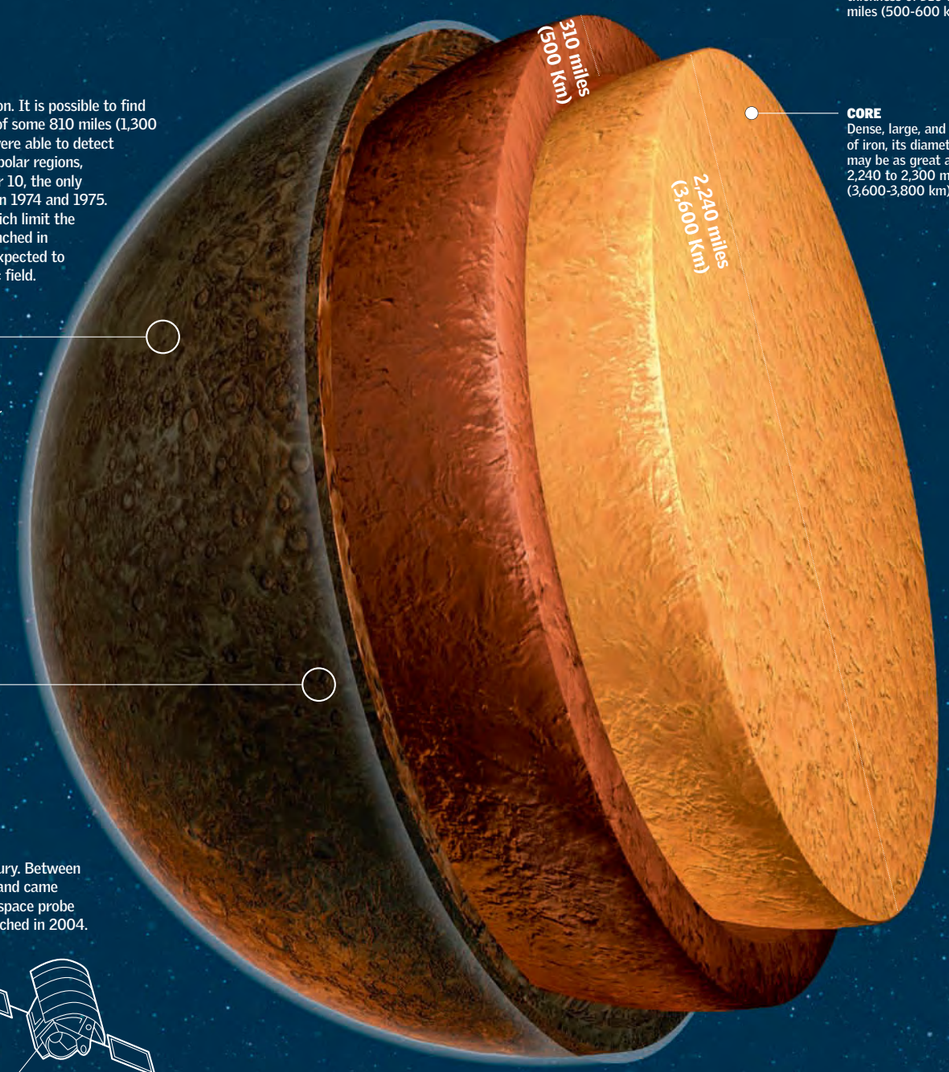
CALORIS CRATER
The largest impact crater in the solar system, it has a diameter of 810 miles (1,300 km).

The crater was flooded with lava.

When the projectile that formed the crater struck, Mercury was still forming. The extensive waves that extended from the site of impact formed hills and mountains ranges.

BEETHOVEN
is the second largest crater on Mercury. It is 400 miles (643 km) in diameter. Its floor was flooded by lava and later marked by meteorite impacts.





CRUST
Made of silicate rocks, Mercury's crust is similar to the crust and mantle of the Earth. It has a thickness of 310 to 370 miles (500-600 km).

CORE
Dense, large, and made of iron, its diameter may be as great as 2,240 to 2,300 miles (3,600-3,800 km).

Missions to Mercury

The space probe Mariner 10 was the first to reach Mercury. Between 1974 and 1975, the craft flew by the planet three times and came within about 200 miles (320 km) of the surface. Messenger, a space probe scheduled to study Mercury between 2008 and 2011, was launched in 2004.

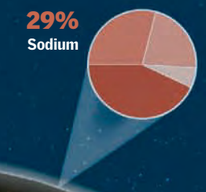
Mariner 10

Messenger

The probe will pass by Mercury twice in 2008 and once again in 2009 before beginning to orbit the planet.

Composition and Magnetic Field

Like the Earth, Mercury has a magnetic field, although a much weaker one. The magnetism results from its enormous core made of solid iron. The mantle that surrounds the core is believed to be a fine layer of iron and sulfur.



EXTREMELY THIN ATMOSPHERE
Mercury's atmosphere is almost nonexistent and consists of a very thin layer that cannot protect the planet either from the Sun or from meteorites. During the day, when Mercury is closer to the Sun, the planet's temperature can surpass 842° F (450° C). At night, temperatures can plummet to -297° F (-183° C).

During the night, the heat of Mercury's rocks is lost rapidly, and the planet's temperature drops.

During the day, the Sun directly heats the rock.

-297° F (-183° C)

883° F (473° C)

MANTLE
Made up mostly of silica-based rocks

333° F (167° C)

Baked by its neighbor the Sun, Mercury is the planet with the greatest thermal fluctuations in the solar system. Its average temperature is 333° F (167° C), but when it gets closer to the Sun, the temperature can climb to 842° F (450° C). At night, it drops to -297° F (-183° C).

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from the Sun	36,000,000 miles (57,900,000 km)
Solar orbit (Mercurian year)	88 days 00 hours
Equatorial diameter	3,032 miles (4,880 km)
Orbital speed	29.75 miles per second (47.87 km/s)
Mass*	0.06
Gravity*	0.38
Density	3.14 ounces per cubic inch (5.43 g/cu cm)
Average temperature	332° F (167° C)
Atmosphere	Almost nonexistent
Lunas	

*In both cases, Earth = 1

AXIS INCLINATION

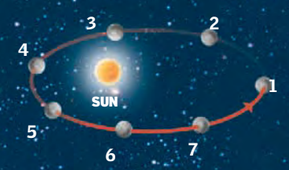
0.1°

One rotation lasts 59 days.

Rotation and Orbit

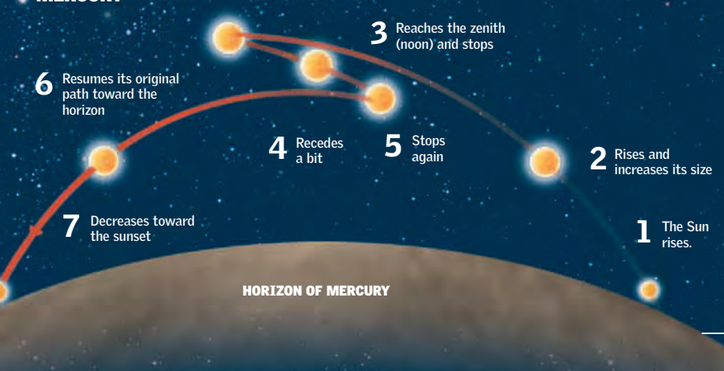
Mercury rotates slowly on its axis and takes approximately 59 Earth days to complete a turn, but it only needs 88 days to travel in its orbit. To an observer in Mercury, these two combined motions would give a combined interval of 176 days between two sunrises. A person observing the sunrise from position 1 would have to wait for the planet to make two orbits around the Sun and make three rotations on its own axis before seeing the next sunrise.

ORBIT OF MERCURY AROUND THE SUN

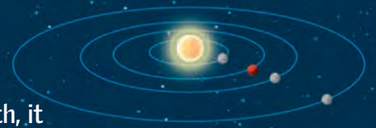


Each number corresponds to a position of the Sun in the sky as seen from Mercury.

VIEW FROM MERCURY



Venus, Our Neighbor



Venus is the second closest planet to the Sun. Similar in size to the Earth, it has a volcanic surface, as well as a hostile atmosphere governed by the effects of carbon dioxide. Although about four billion years ago the atmospheres of the Earth and Venus were similar, the mass of Venus's atmosphere today is 100 times greater than the Earth's. Its thick clouds of sulfuric acid and dust are so dense that stars are invisible from the planet's surface. Viewed from the Earth, Venus can be bright enough to be visible during day and second only to the moon in brightness at night. Because of this, the movements of Venus were well-known by most ancient civilizations.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL ♀

ESSENTIAL DATA

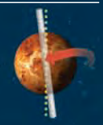
Average distance from the Sun	67,000,000 miles (108,000,000 km)
Solar orbit (Venusian year)	224 days 17 hours
Equatorial diameter	7,520 miles (12,100 km)
Orbital speed	22 miles per second (35 km/s)
Mass*	0.8
Gravity*	0.9
Density	3.03 ounces per cubic inch (5.25 g/cu cm)
Average temperature	860° F (460° C)
Atmosphere	Very thick
Moons	None

*In both cases, Earth = 1

AXIS INCLINATION

117°

Rotates on its own axis every 243 days



Composition

The overwhelming presence of carbon dioxide in the Venusian atmosphere induces a greenhouse effect, increasing the surface temperature to 864° F (462° C). Because of this, Venus is hotter than Mercury, even though Venus is farther from the Sun and reflects all but 20 percent of the Sun's light. The surface temperature of Venus is relatively constant, averaging 860° F (460° C). The atmospheric pressure on Venus is 90 times greater than that on the Earth.

ATMOSPHERE
Venus's glowing appearance is caused by the planet's thick, suffocating atmosphere, which is made up of carbon dioxide and sulfuric clouds that reflect sunlight.

50 miles (80 km) IS THE THICKNESS OF THE ATMOSPHERE.

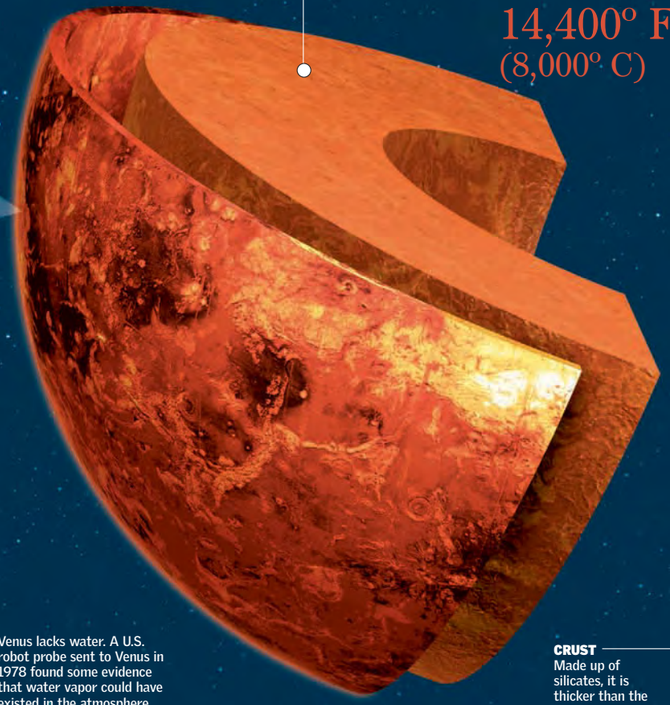
MANTLE
Made of molten rock, it constitutes most of the planet. It traps the solar radiation and is between 37 and 62 miles (60 and 100 km) thick.

CORE
It is believed that Venus's core is similar to the Earth's, containing metallic elements (iron and nickel) and silicates. Venus has no magnetic field—possibly because of its slow axial rotation.

14,400° F (8,000° C)

Carbon dioxide **97%**

Nitrogen and traces of other gases **3%**

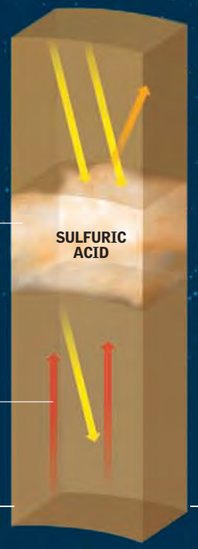


GREENHOUSE EFFECT
Only 20 percent of the Sun's light reaches the surface of Venus. The thick clouds of dust, sulfuric acid, and carbon dioxide that constitute Venus's atmosphere reflect the remaining light, leaving Venus in permanent darkness.

SOLAR RADIATION
Venus is kept hot by its thick atmosphere, which retains the energy of the Sun's rays.

864° F (462° C)

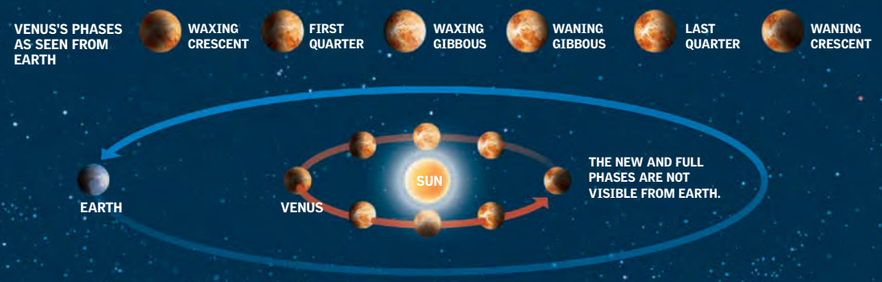
INFRARED RAYS
The surface of Venus radiates infrared radiation. Only 20 percent of the Sun's rays pass through Venus's thick clouds of sulfuric acid.



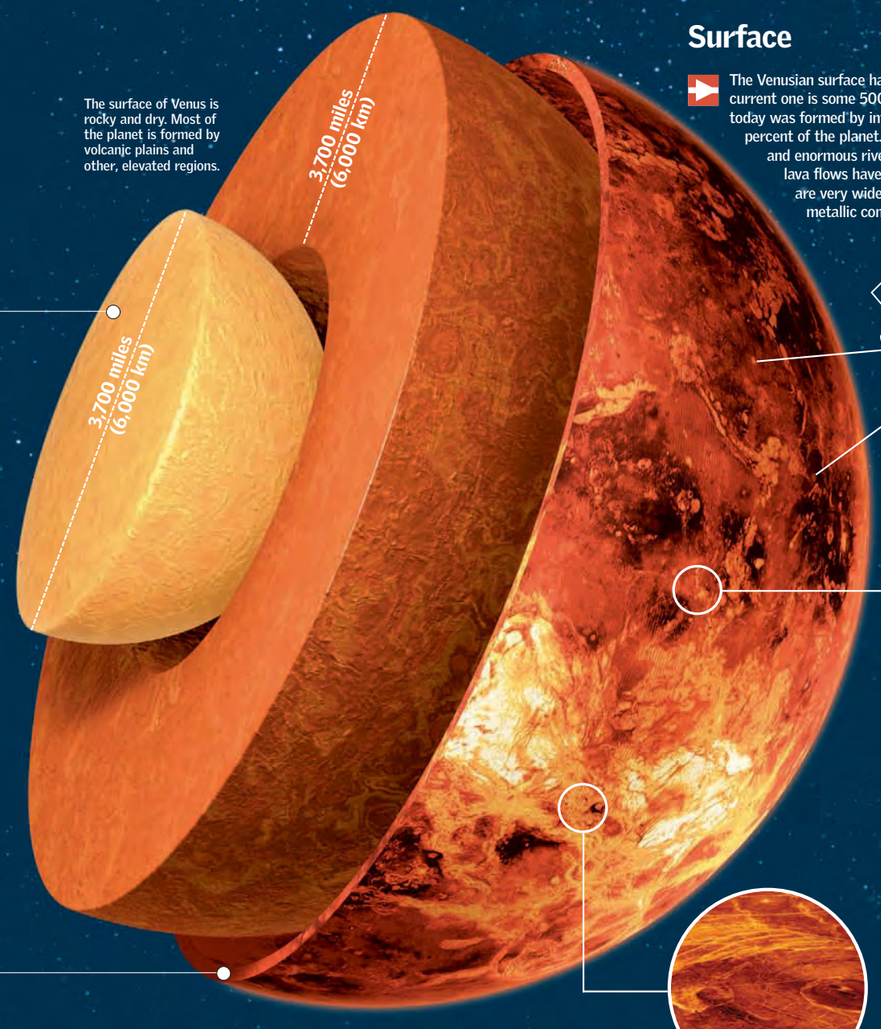
Venus lacks water. A U.S. robot probe sent to Venus in 1978 found some evidence that water vapor could have existed in the atmosphere hundreds of millions of years ago, but today no trace of water remains.

VENUS'S PHASES

As Venus revolves around the Sun, its solar illumination varies as is seen from the Earth depending upon its position in relation to the Sun and the Earth. Thus Venus has phases similar to the Moon's. During its elongations, when Venus is farthest from the Sun in the sky, Venus appears at its brightest.



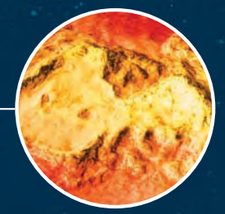
The surface of Venus is rocky and dry. Most of the planet is formed by volcanic plains and other, elevated regions.



Surface

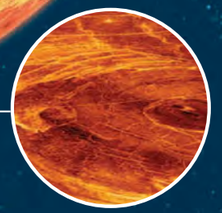
The Venusian surface has not remained the same throughout its life. The current one is some 500 million years old, but the rocky landscape visible today was formed by intense volcanic activity. Volcanic rock covers 85 percent of the planet. The entire planet is crisscrossed by vast plains and enormous rivers of lava, as well as a number of mountains. The lava flows have created a great number of grooves, some of which are very wide. The brightness of Venus's surface is the result of metallic compounds.

MAGELLAN
Venus was explored by the Magellan spacecraft between 1990 and 1994. The probe was equipped with a radar system to observe the surface through its dense atmosphere.



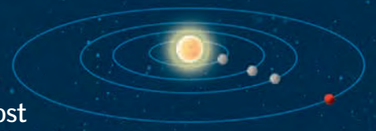
ISHTAR TERRA
One of the raised plateaus of Venus, it is similar in size to Australia and is located close to Venus's north pole. It has four main rocky mountain ranges called Maxwell Montes, Freyja Montes, Akna Montes, and Dam Montes.

CRUST
Made up of silicates, it is thicker than the Earth's crust.



APHRODITE TERRA
Larger than Ishtar Terra, it is the size of South America. Aphrodite Terra lies near the equator and consists mostly of mountainous regions to the east and west, which are separated by a low-lying region.

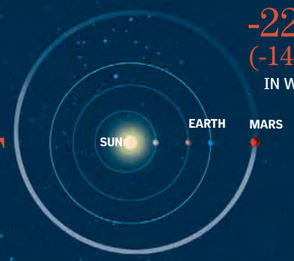
Red and Fascinating



Mars is the fourth planet from the Sun. Of all the planets, Mars most closely resembles the Earth. It has polar ice caps, and the tilt of its axis, period of rotation, and internal structure are similar to those of the Earth. Known as the Red Planet because of the reddish iron oxide that covers its surface, Mars has a thin atmosphere composed essentially of carbon dioxide. Mars does not have water, though it did in the past, and there is evidence some water might exist underground. Many spacecraft have been sent to explore Mars, in part because it is the planet other than Earth most likely to have developed some form of life, and it will probably be the first planet humans leave the Earth to visit.

Martian Orbit

Because Mars's orbit is more elliptical than that of Earth, Mars's distance from the Sun varies widely. At its perihelion, or closest approach to the Sun, Mars receives 45 percent more solar radiation than at its aphelion, or farthest point. Temperatures on Mars range from -220° F to 62° F (-140° C to 17° C).



Moons

Mars has two moons, Phobos and Deimos. Both have a lower density than Mars and are pitted with craters. Phobos has a diameter of 17 miles (27 km), and Deimos has a diameter of nine miles (15 km). Deimos orbits Mars in 30 hours at an altitude of 14,627 miles (23,540 km), and Phobos orbits Mars in eight hours at an altitude of 5,840 miles (9,400 km). Astronomers believe that the moons are asteroids that were captured by Mars's gravity.

DEIMOS

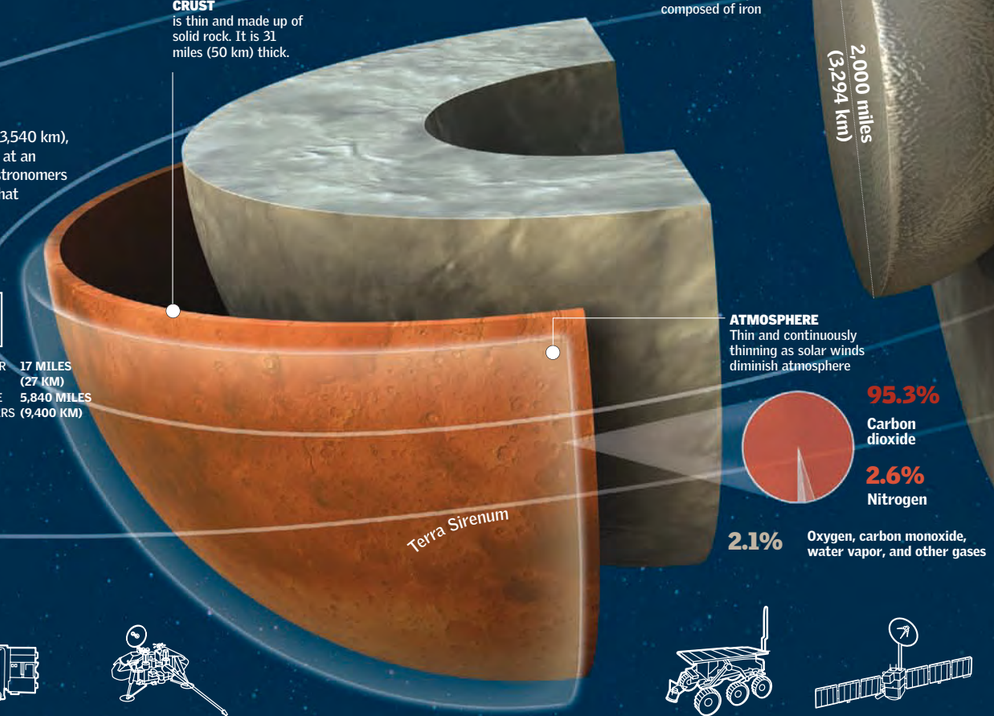
DIAMETER 9 MILES (15 KM)
DISTANCE FROM MARS 14,627 MILES (23,540 KM)

PHOBOS

DIAMETER 17 MILES (27 KM)
DISTANCE FROM MARS 5,840 MILES (9,400 KM)

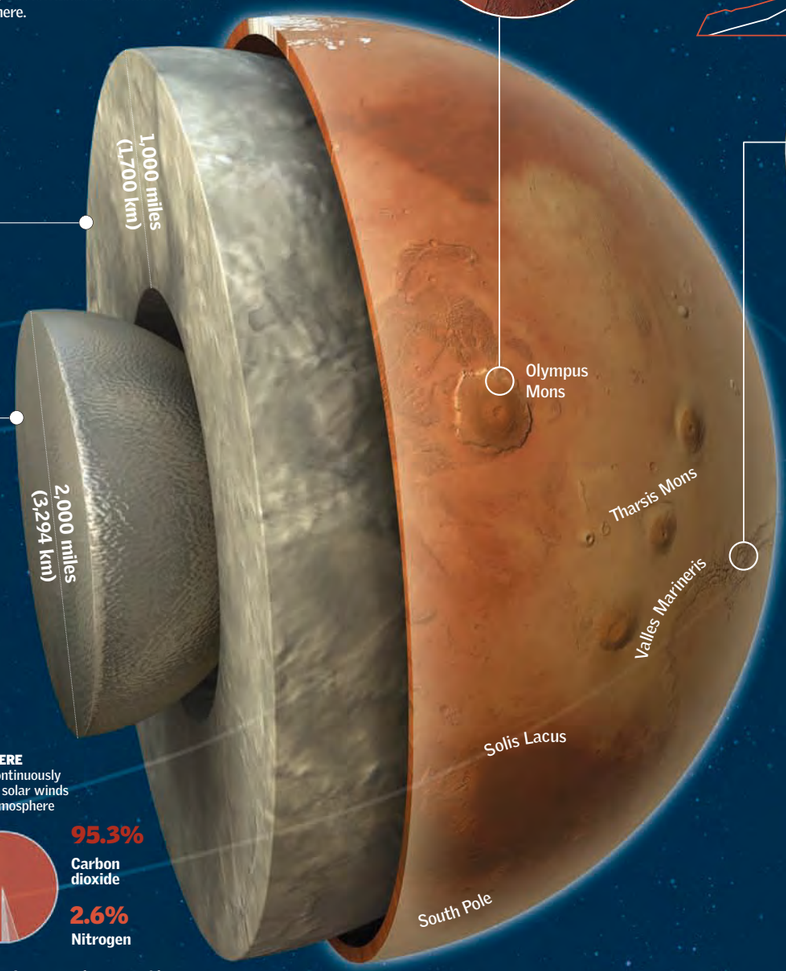
Composition

Mars, a rocky planet, has an iron-rich core. Mars is almost half the size of the Earth and has a similar period of rotation, as well as clearly evident clouds, winds, and other weather phenomena. Its thin atmosphere is made up of carbon dioxide, and its red color comes from its soil, which is rich in iron oxide.



Surface

It is a place of geologic extremes, shaped by volcanic activity, meteorite bombardment, windstorms, and floods (though there is little or no water on Mars today). Mountains dominate the southern hemisphere, but lowlands are common in the northern hemisphere.



OLYMPUS MONS
This gigantic, inactive volcano is not only the largest on Mars but also in the solar system.

VALLES MARINERIS

The canyon system of the Valles Marineris was likely caused naturally, primarily by water erosion.

CHARACTERISTICS

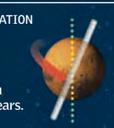
CONVENTIONAL PLANET SYMBOL ♂

ESSENTIAL DATA

Average distance from the Sun	141,600,000 miles (227,900,000 km)
Solar orbit (Martian year)	1.88 years
Equatorial diameter	4,222 miles (6,794 km)
Orbital speed	15 miles per second (24 km/s)
Mass*	0.107
Gravity*	0.38
Density	2.27 ounces per cubic inch (3.93 g/cu cm)
Average temperature	-81° F (-63° C)
Atmosphere	Very thin
Moons	2

*In both cases, Earth = 1

AXIS INCLINATION



25.2°

One rotation lasts 1.88 years.

MISSIONS TO MARS

After our own Moon, Mars has been a more attractive target for exploratory missions than any other object in the solar system.

1965 MARINER 4
The first mission sent to Mars, it made only brief flyovers.

1969 MARINER 6 AND 7 studied the southern hemisphere and equator of Mars.

1971 MARINER 9 photographed the Olympus volcano for the first time.

1973 MARS 4, MARS 5, MARS 6, AND MARS 7
Russian spacecraft successfully sent to Mars

1976 VIKING 1 AND 2
searched for traces of life. They were the first spacecraft to land on Martian soil.

1997 MARS PATHFINDER was the third successful Mars landing.

1997 MARS GLOBAL SURVEYOR took more than 100,000 photos of the planet.

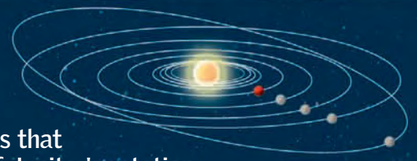
2001 MARS ODYSSEY
mapped the mineralogy and morphology of Mars's surface.

2003 MARS EXPRESS
Orbiting probe. First spacecraft sent by the European Space Agency.

2004 SPIRIT AND OPPORTUNITY
surveyed many square miles of the surface.

2006 MARS RECONNAISSANCE ORBITER made a detailed study of the Martian surface while orbiting the planet.

Jupiter, Gas Giant



Jupiter is the largest planet in the solar system. Its diameter is 11 times that of the Earth, and its mass is 300 times as great. Because the speed of Jupiter's rotation flattens the planet at its poles, its equatorial diameter is greater than its polar diameter. Jupiter rotates at 25,000 miles per hour (40,000 km/hr). One of the most distinctive elements of Jupiter's atmosphere is its so-called Great Red Spot, a giant high-pressure region of turbulence that has been observed from the Earth for more than 300 years. The planet is orbited by numerous satellites and has a wide, faint ring of particles.

Composition

Jupiter is a giant ball of hydrogen and helium that have been compressed into liquid in the planet's interior and into metallic rock in its core. Not much is known about Jupiter's core, but it is believed to be bigger than the Earth's core.

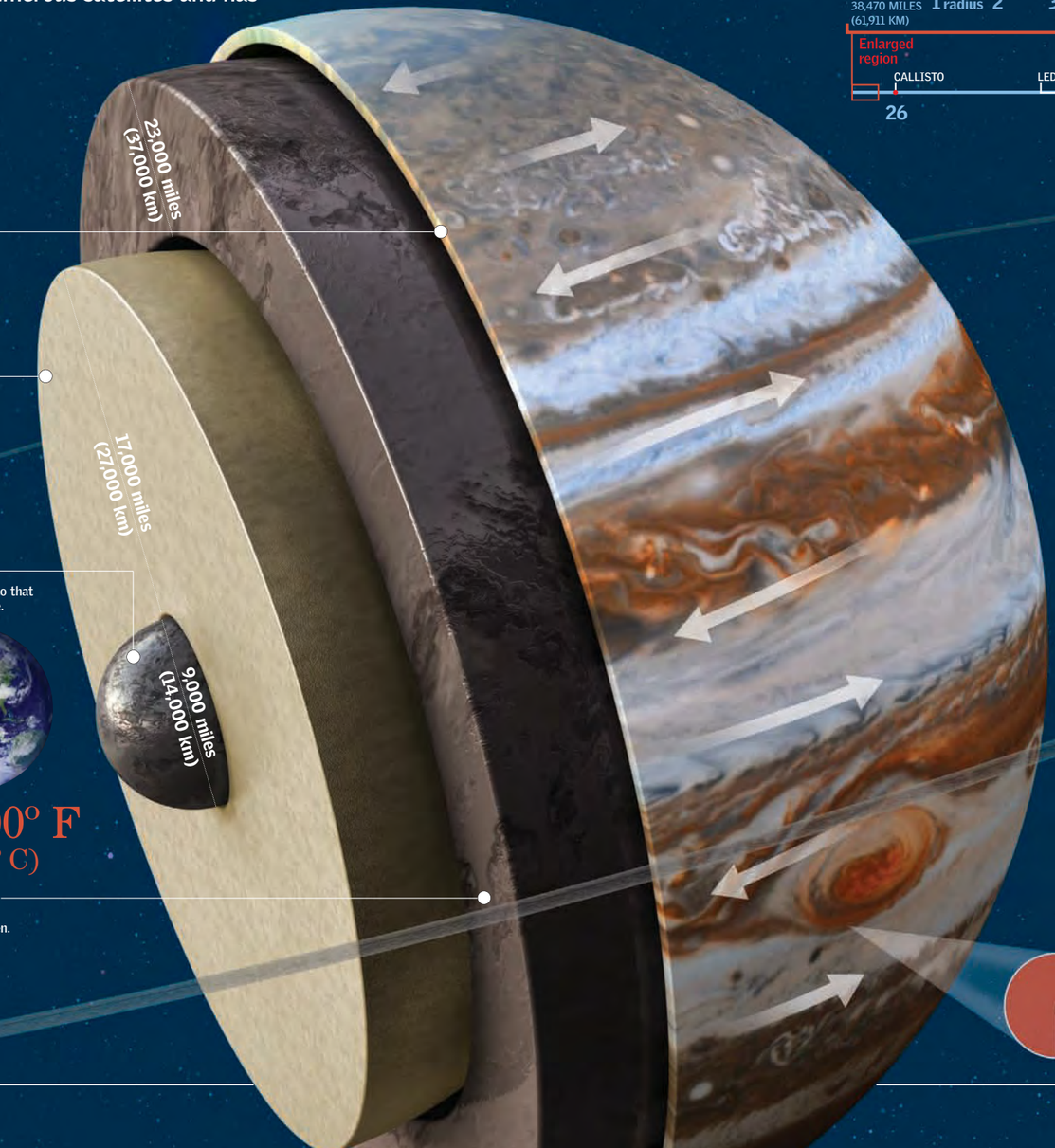
ATMOSPHERE
measures 620 miles (1,000 km).

INNER MANTLE
Surrounds the core. It is made of liquid metallic hydrogen, an element only found under hot, high-pressure conditions. The inner mantle is a soup of electrons and nuclei.

CORE
Its size is similar to that of the Earth's core.

54,000° F
(30,000° C)

OUTER MANTLE
Made of liquid molecular hydrogen. The outer mantle merges with the atmosphere.



CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from the Sun	483,000,000 miles (778,000,000 km)
Solar orbit (Jovian year)	11 years 312 days
Equatorial diameter	88,700 miles (142,800 km)
Orbital speed	8 miles per second (13 km/s)
Mass*	318
Gravity*	2.36
Density	0.77 ounce per cubic inch (1.33 g/cu cm)
Average temperature	-184° F (-120° C)
Atmosphere	Very dense
Moons	More than 60

*In both cases, Earth = 1

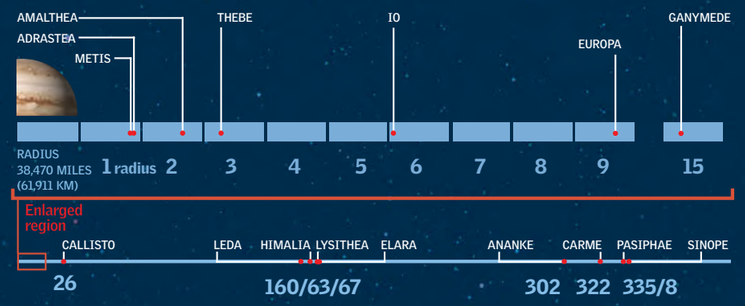
AXIS INCLINATION

3.1°

One rotation lasts 9 hours and 55 minutes.

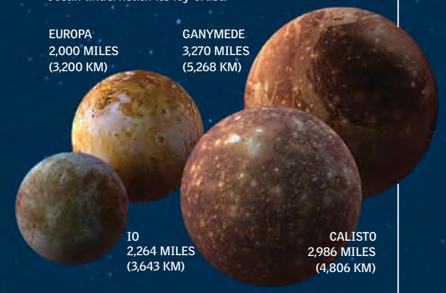
The Moons of Jupiter

Jupiter has more than 60 moons. Many of them have not been officially confirmed and do not even have names. Jupiter's rotation is gradually slowing because of the moons' tidal effects.



GALILEAN MOONS

Of Jupiter's 63 moons, four are visible from Earth with binoculars. These are called the Galilean moons in honor of their discoverer, Galileo Galilei. Astronomers believe that Io has active volcanoes and that Europa has an ocean underneath its icy crust.



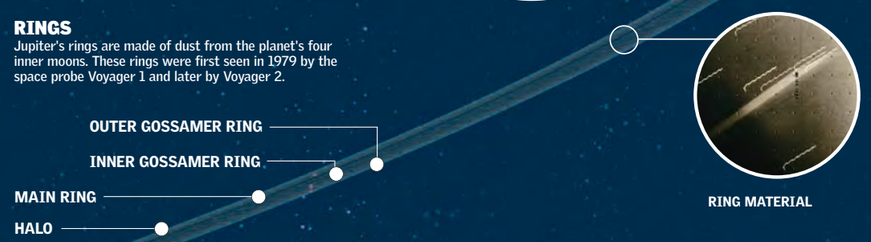
Winds

The winds on Jupiter blow in contiguous bands and opposing directions. The bands' small differences in temperature and chemical composition give the planet its multicolored appearance. Jupiter's inclement environment, in which winds blow at more than 370 miles per hour (600 km/h), can cause large storms, such as the Great Red Spot in the southern hemisphere of the planet. The Great Red Spot, which is 16,155 miles (26,000 km) long, is believed to be composed mainly of ammonia gas and clouds of ice.

16,160 miles
(26,000 km)
GREAT RED SPOT

RINGS

Jupiter's rings are made of dust from the planet's four inner moons. These rings were first seen in 1979 by the space probe Voyager 1 and later by Voyager 2.



ATMOSPHERE

surrounds the inner liquid layers and the solid core. It is 620 miles thick (1,000 km).

89.8%
Hydrogen

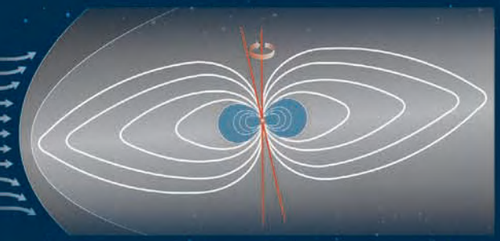
10.2%
Helium
With traces of methane and ammonia

JUPITER'S MAGNETISM

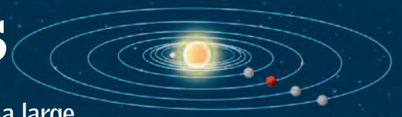
Jupiter's magnetic field is 20,000 times stronger than the Earth's. Astronomers believe the field is caused by the electrical currents that are created by the rapid rotation of metallic hydrogen. Jupiter is surrounded by a huge magnetic bubble, the magnetosphere. The magnetosphere's tail reaches more than 370,000,000 miles (600,000,000 km)—beyond the orbit of Saturn.

Jupiter's magnetosphere is the largest object in the solar system. It varies in size and shape in response to the solar wind, which is composed of the particles continuously radiated from the Sun.

400,000,000 miles
(650,000,000 km)



The Lord of the Rings



Saturn is the solar system's second largest planet. Like Jupiter, it is a large ball of gas surrounding a small, solid core. Saturn was the most distant planet discovered before the invention of the telescope. To the naked eye, it looks like a yellowish star, but with the help of a telescope, its rings are clearly visible. Ten times farther from the Sun than the Earth, Saturn is the least dense planet. If an ocean could be found large enough to hold it, Saturn would float.

Rings

Saturn's rings, the brightest rings in the solar system, are made of rock and ice and orbit Saturn's equator. The rings are probably remains of destroyed comets that were trapped by Saturn's gravitational field.

RINGS G AND E

310 miles (500 km)

9100 miles (14,600 km)

ENCKE DIVISION
A small gap that separates ring A into two parts

F RING
The farthest visible ring

A RING
Saturn's outer ring

CASSINI DIVISION
3,100 miles (5,000 km) wide, it is located between the A and B rings.

B RING
Saturn's brightest and widest ring

C RING
Saturn's only transparent ring

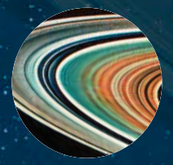
D RING
The closest ring to the surface of Saturn—so near that it almost touches the planet

15,800 miles (25,500 km)

10,900 miles (17,500 km)

5,300 miles (8,500 km)

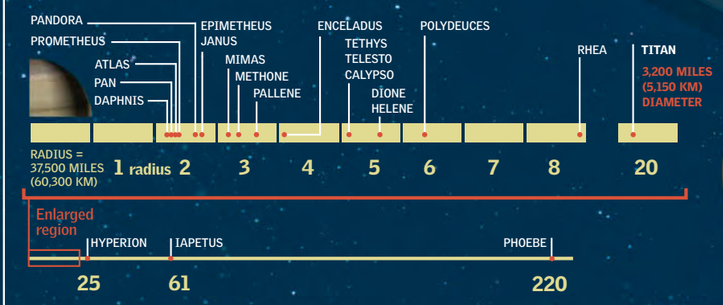
2,200 miles (3,500 km)



THICKNESS AND WIDTH
Although Saturn's rings are very wide, their thickness is sometimes less than 33 feet (10 m).

The Moons of Saturn

Saturn has more than 45 moons, making Saturn's family of moons one of the largest in the solar system. The sizes of the moons vary from Titan's 3,200 miles (5,150 km) to tiny Calypso's 10 miles (16 km).



Titan has a larger diameter than Mercury. It has an atmosphere that is mostly made of nitrogen.

Surface

Like Jupiter, Saturn has a surface of clouds that form bands because of the planet's rotation. Saturn's clouds are less turbulent and less colorful than Jupiter's. The higher, white clouds reach temperatures of -220° F (-140° C). A layer of haze extends above the clouds.

WINDS
Saturn's winds generally reach speeds of about 220 miles per hour (360 km/h), causing strong storms.

Gaseous Exterior

Saturn and Jupiter differ very little in their composition. Both are gaseous balls surrounding solid cores. What sets Saturn apart are its rings, formed by clustered pieces of ice that range in size from small particles to large chunks. Each particle in a ring is a satellite orbiting Saturn. From the Earth, the massed debris seems to form large structures, but each discrete piece actually has its own orbit.

ATMOSPHERE

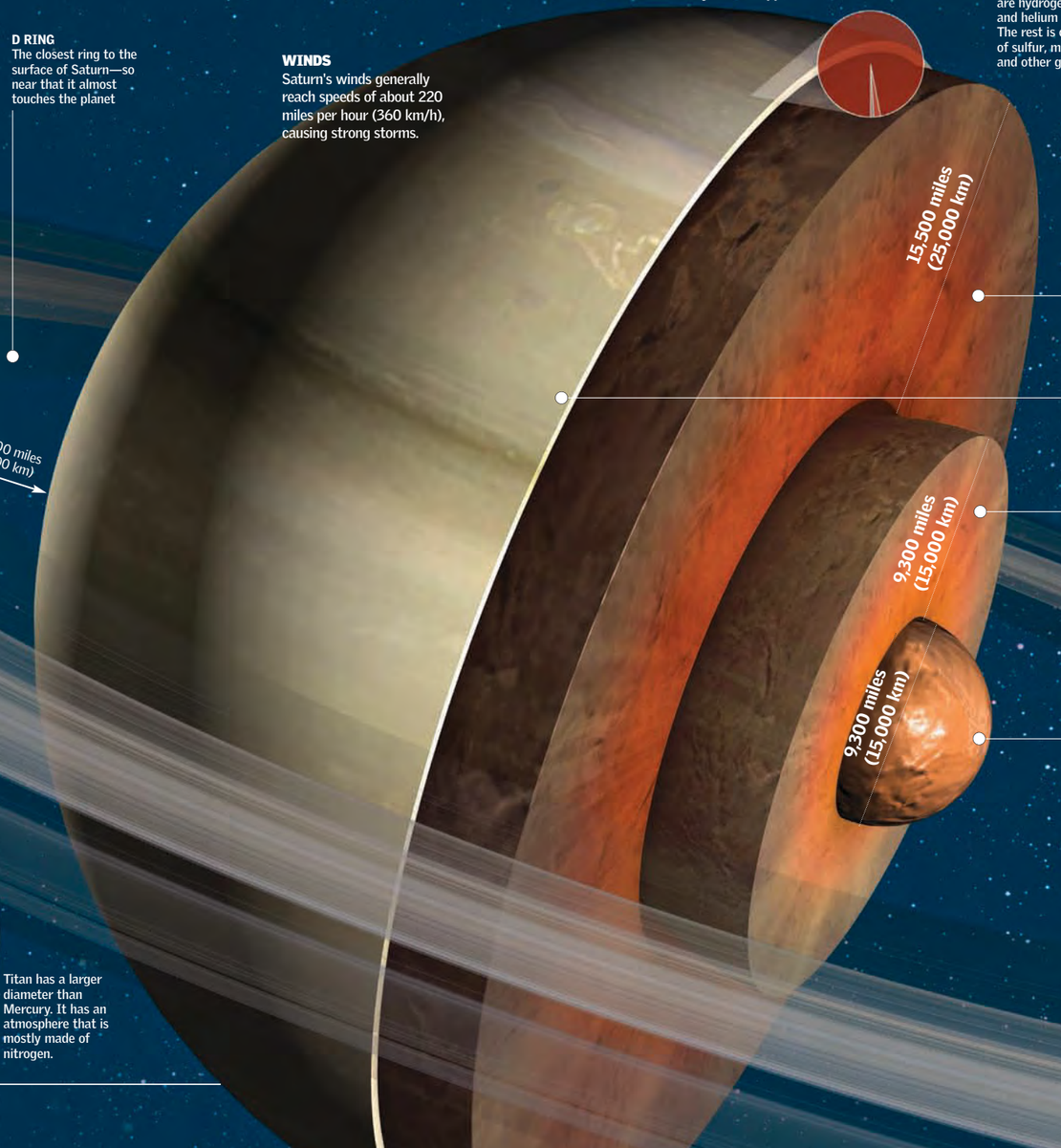
<1%
Sulfur gives it a yellowish appearance.

2%
Helium

97%
Hydrogen

COMPONENTS

The main components of Saturn's atmosphere are hydrogen (97%) and helium (2%). The rest is composed of sulfur, methane, and other gases.



OUTER MANTLE
This layer is formed by liquid molecular hydrogen.

ATMOSPHERE
Mainly hydrogen and helium

INNER MANTLE
It is made up of liquid metallic hydrogen.

CORE
Composed of rock and metallic elements, such as silicates and iron

21,600°F (12,000° C)

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from the Sun	887,000,000 miles (1,427,000,000 km)
Solar orbit (Saturnine year)	29 years 154 days
Equatorial diameter	74,940 miles (120,600 km)
Orbital speed	6 miles per second (10 km/s)
Mass*	95
Gravity*	0.92
Density	0.4 ounce per cubic inch (0.7 g/cu cm)
Average temperature	-193° F (-125° C)
Atmosphere	Very dense
Moons	More than 45

*In both cases, Earth = 1

AXIS INCLINATION

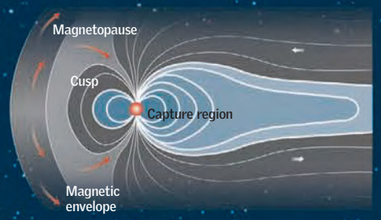
26.7°
One rotation lasts 10 hours and 39 minutes.

Uranus Without Secrets

To the unaided eye, Uranus looks like a star at the limit of visibility. It is the seventh farthest planet from the Sun and the third largest planet in the solar system. One peculiarity distinguishing it from the other planets is its anomalous axis of rotation, tilted nearly 98 degrees around the plane of its orbit, so that one or the other of Uranus's poles points toward the Sun. Astronomers speculate that, during its formation, Uranus may have suffered an impact with a protoplanet, which could have altered Uranus's tilt. Uranus's orbit is so large that the planet takes 84 years to completely orbit the Sun. Uranus's period of rotation is 17 hours and 14 minutes.

MAGNETIC FIELD

Uranus generates a magnetic field 50 times more powerful than Earth's. This field is not centered on the planet, but is offset and tilted 60 degrees from Uranus's axis. If this were the case on Earth, the magnetic north pole would be located in Morocco. Unlike other planets, Uranus's magnetic field originates in the planet's mantle, not its core.



Some scientists suggest that Uranus's anomalous magnetic field may indicate that the convection of Uranus's core has stopped because of cooling—or, perhaps, that the planet is currently undergoing a magnetic inversion, as has happened on the Earth.

Composition

Uranus's core is made of abundant amounts of silicates and ice. The planet is almost four times larger than the Earth, and its atmosphere is made up of hydrogen, helium, and methane. Uranus has an almost horizontal tilt, causing it to have very long seasons.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

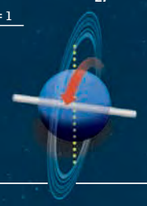
ESSENTIAL DATA	
Average distance from the Sun	1,780,000,000 miles (2,870,000,000 km)
Solar orbit (Uranian year)	84 years 4 days
Equatorial diameter	32,200 miles (51,800 km)
Orbital speed	4 miles per second (7 km/s)
Mass*	14.5
Gravity*	0.89
Density	0.8 ounce per cubic inch (1.3 g/cu cm)
Average temperature	-346° F (-210° C)
Atmosphere	Less dense
Moons	27

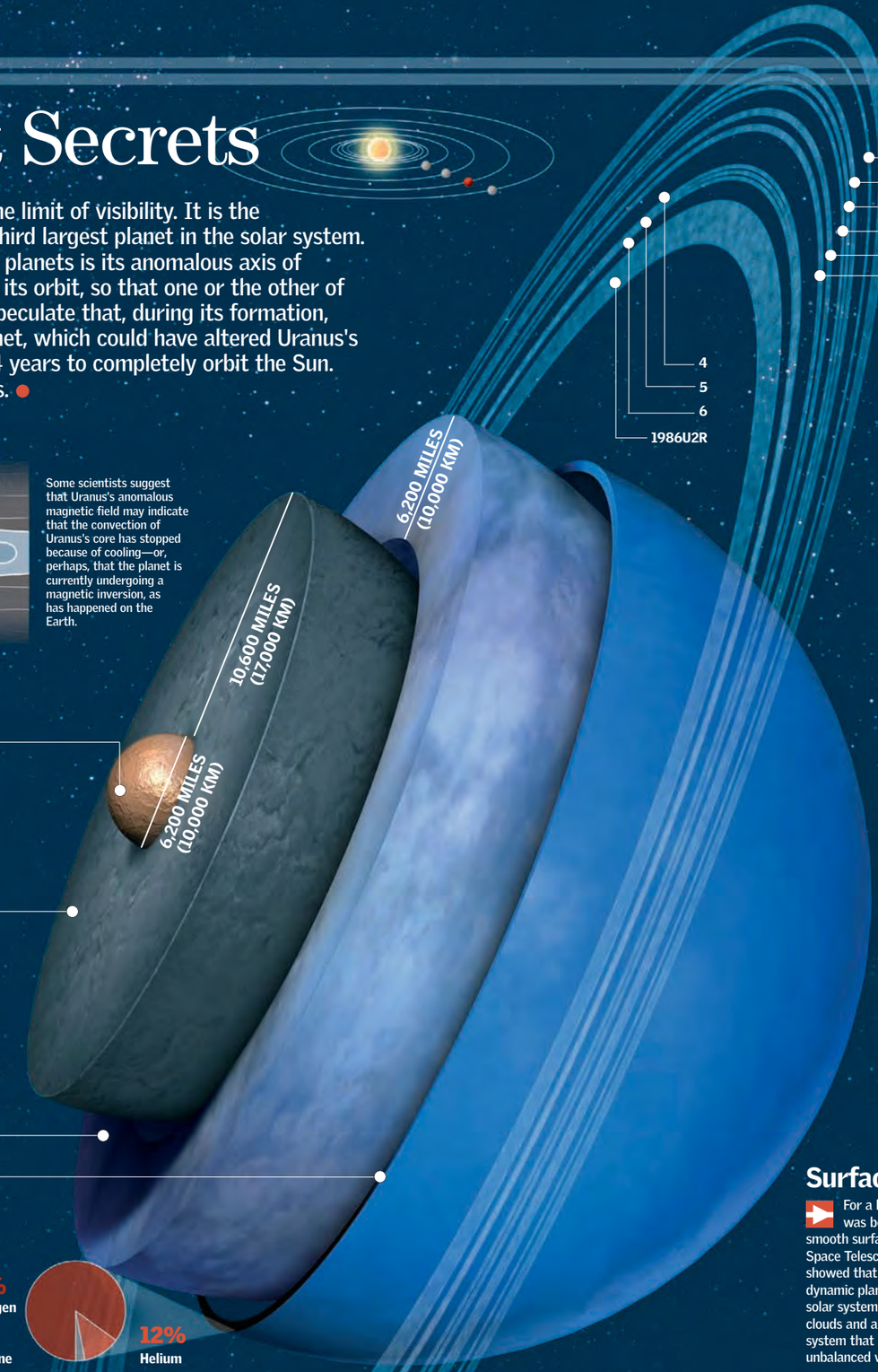
* In both cases, Earth = 1

AXIS INCLINATION

97.9°

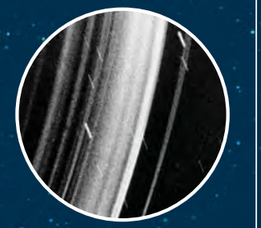
One rotation lasts 17 hours and 14 minutes.





Rings

Like all giant planets of the solar system, Uranus has a ring system, but it is much darker than Saturn's and more difficult to see. The planet's 11 rings, which orbit the planet's equator, were discovered in 1977. In 1986, they were explored by Voyager 2.



Satellites

Uranus has 27 moons. The first four were discovered in 1787, and another 10 were identified in 1986 by the space probe Voyager 2. Uranus's moons were named in honor of characters from the works of William Shakespeare and Alexander Pope, a naming convention that distinguishes them from the other moons in the solar system. Some of Uranus's moons are large, but most measure only dozens of miles.

MOONS

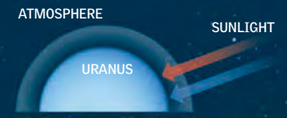
Uranus has small, dark moons, discovered by Voyager 2, as well as bigger moons, such as Miranda, Ariel, Umbriel, Oberon, and Titania. These last two are approximately 930 miles (1,500 km) in diameter.

Surface

For a long time, Uranus was believed to have a smooth surface. The Hubble Space Telescope, however, showed that Uranus is a dynamic planet that has the solar system's brightest clouds and a fragile ring system that wobbles like an unbalanced wheel.

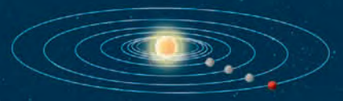
REFRACTION OF RAYS

1. In Uranus, sunlight is reflected by a curtain of clouds that lie underneath a layer of methane.



2. When sunlight passes through this layer, the methane absorbs the red light waves and lets the blue light waves pass through, producing the planet's hue.

Neptune: Deep Blue



Seen from our planet, Neptune appears as a faint, blue point invisible to the naked eye. Images sent to Earth by Voyager 2 show the planet as a remarkably blue sphere, an effect produced by the presence of methane in the outer part of Neptune's atmosphere. The farthest of the gaseous planets, Neptune is 30 times farther from the Sun than the Earth is. Its rings and impressive clouds are noteworthy, as is its resemblance to Uranus. Neptune is of special interest to astronomers because, before its discovery, its existence and location were predicted on the basis of mathematical calculations.

Moons

Neptune has 13 natural satellites, nine of which are named. Triton and Nereid were the first moons observed by telescope from Earth. The 11 remaining moons were observed from space by the U.S. space probe Voyager 2. All the names of Neptune's satellites correspond to ancient Greek marine deities.

TRITON
Its diameter is 1,681 miles (2,706 km). Triton orbits Neptune in a direction opposite that of the other moons. Its surface has dark stripes formed by the material spewed from its geysers and volcanoes.

-391° F
(-235° C)
is its temperature, making Triton one of the coldest bodies in the solar system.

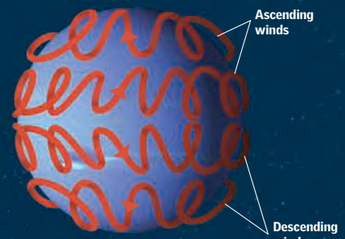
Rings

Uranus has faint rings of dust. When they were discovered from the Earth, astronomers thought the rings formed incomplete arcs. The ring names honor the first scientists to study Neptune.

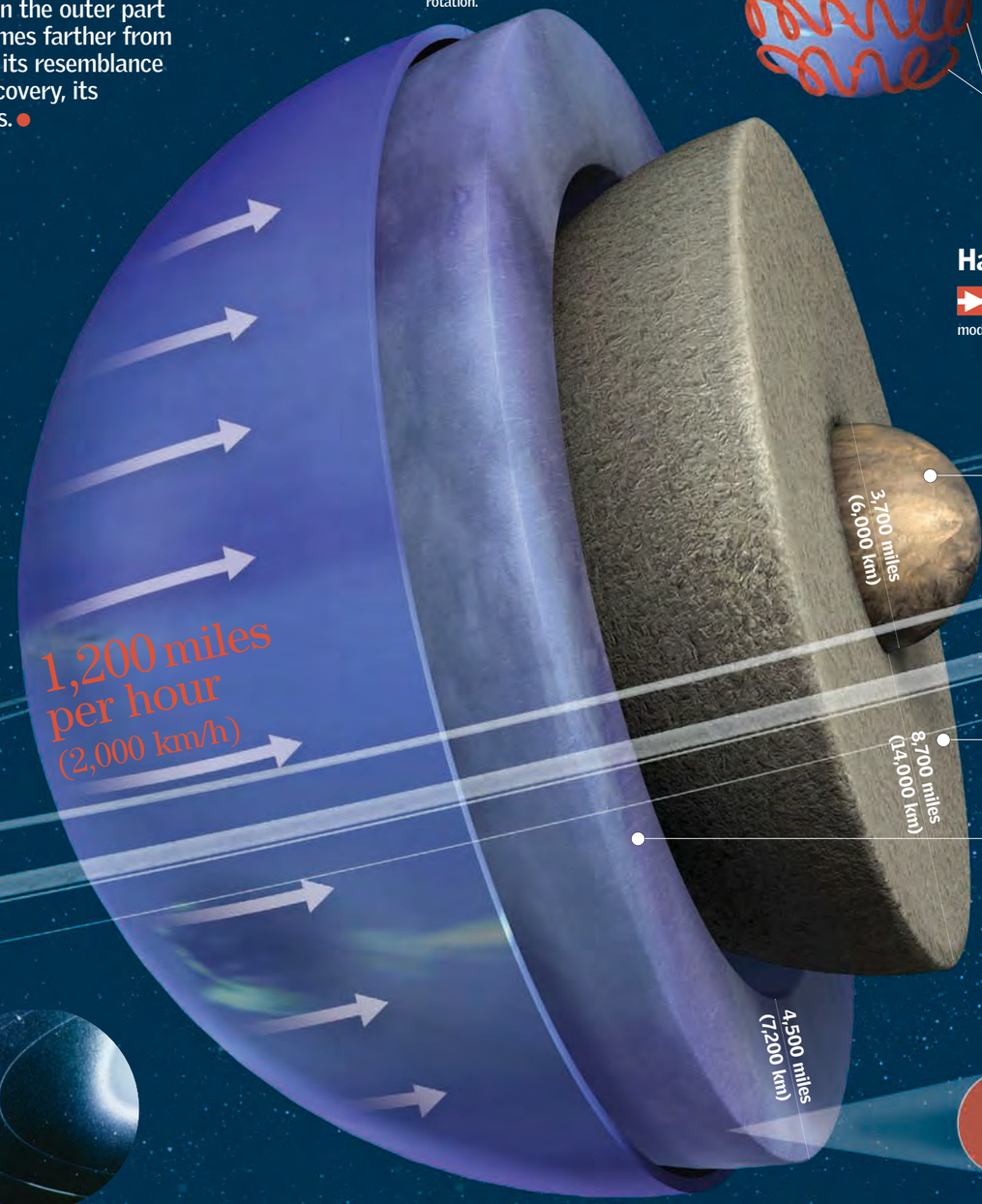
COMPOSITION
Neptune's rings are dark, like those of Uranus and Jupiter. Their composition is unknown, and they are believed to be unstable. Liberty, which makes up part of the outer ring, could vanish before the 22nd century.

Surface

White methane clouds surround Neptune, circulating at some of the fastest speeds in the solar system. Neptune's winds reach 1,200 miles per hour (2,000 km/h) from east to west, swirling against the direction of the planet's rotation.



THE GREAT SPOT
This giant storm, called the Great Dark Spot, was first seen on the surface of Neptune in 1989 and was as large as the Earth. By 1994, it had disappeared.



Hard Heart

According to some models, Neptune has a rocky silicate core, covered by a mantle of icy water, ammonia, hydrogen, and methane. According to some models, however, the materials of the mantle and core do not form layers.

CORE
Made up of silicates and ice

INNER MANTLE
Probably icy water, methane, and ammonia

OUTER MANTLE
Composed primarily of hydrogen and helium, as well as a small amount of methane

ATMOSPHERE
Banded, like the atmospheres of the other gas giants, Neptune's atmosphere forms a cloud system at least as active as Jupiter's.

89.8%
Hydrogen

10.2%
Helium

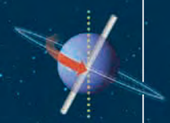
CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA	
Average distance from the Sun	2,800,000,000 miles (4,500,000,000 km)
Solar orbit (Neptunian year)	164 years 264 days
Equatorial diameter	30,800 miles (49,500 km)
Orbital speed	3.4 miles per second (5.5 km/s)
Mass*	17.2
Gravity*	1.12
Density	1 ounce per cubic inch (1.6 g/cu cm)
Average temperature	-330° F (-200° C)
Atmosphere	Dense
Moons	13

*In both cases, Earth = 1

AXIS INCLINATION
28.3°
One rotation lasts 16 hours and 36 minutes.

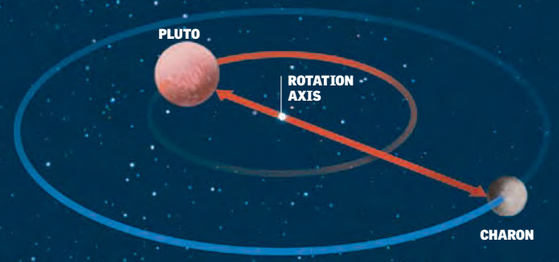


Pluto: Now a Dwarf

Pluto stopped being the ninth planet of the solar system in 2006 when the International Astronomical Union decided to change the classification of cold, distant Pluto to that of dwarf planet. This tiny body in our solar system has never had an imposing profile, and it has not yet been possible to study it closely. All that is known about Pluto comes through observations made from the Earth or Earth orbit, such as those made by the Hubble Space Telescope. Despite the lack of information gathered about Pluto, it is notable for its unique orbit, the tilt of its axis, and its location within the Kuiper belt. All these characteristics make Pluto especially intriguing.

A Double World

Pluto and its largest satellite, Charon, have a very special relationship. They have been called double planets—the diameter of Charon is about that of Pluto. One theory hypothesizes that Charon was formed from ice that was torn from Pluto when another object collided with the dwarf planet.



SYNCHRONIZED ORBITS

The orbital arrangement of Pluto and Charon is unique. Each always faces the other, making the two seem connected by an invisible bar. The synchronization of the two bodies is such that an observer on one side of Pluto would be able to see Charon, but another observer standing on the other side of the planet could not see this moon due to the curvature of the planet.

Surface

Only a little is known about Pluto, but the Hubble Space Telescope showed a surface covered by a frozen mixture of nitrogen and methane. The presence of solid methane indicates that its temperature is less than -333° F (-203° C), but the dwarf planet's temperature varies according to its place in orbit, ranging between 30 and 50 astronomical units from the Sun.

BEST VIEW OF PLUTO AVAILABLE

Moons

In addition to Charon, which was discovered in 1978, Pluto is orbited by two additional moons, Nix and Hydra, first observed in 2005. Unlike the surface of Pluto, which is made of frozen nitrogen, methane, and carbon dioxide, Charon appears to be covered with ice, methane, and carbon dioxide. One theory holds that the matter that formed this satellite was ejected from Pluto as a result of a collision, an origin similar to that ascribed to Earth's moon.

DENSITY
Charon's density is between 0.7 and 0.8 ounce per cubic inch (1.2 and 1.3 g/cu cm), indicating that its composition does not include much rock.

730 miles (1,172 km)
Charon's diameter—half of Pluto's

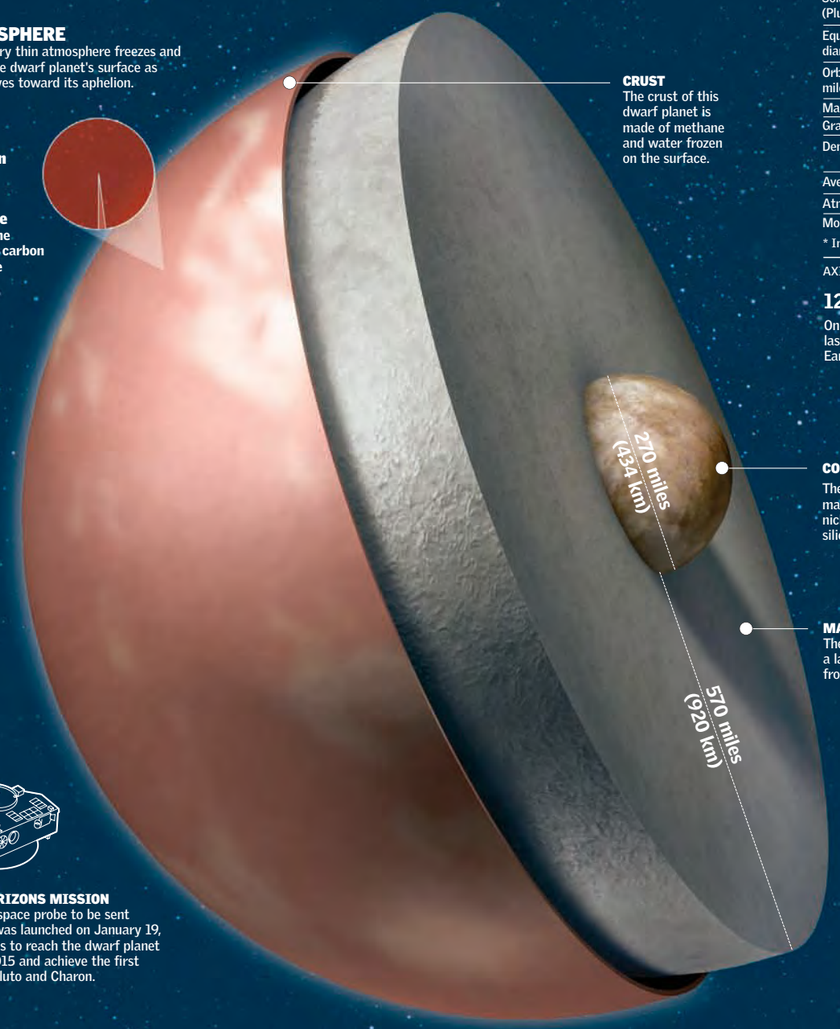
Composition

Scientific calculations have deduced that 75 percent of Pluto consists of a mixture of rocks and ice. This frozen surface is made up of 98 percent nitrogen, as well as traces of solidified carbon monoxide and methane. Recently scientists have concluded that Pluto is an object that belongs to the Kuiper belt, a group of objects left over from the formation of the outer planets. In addition to large amounts of frozen nitrogen, Pluto has simple molecules containing hydrogen and oxygen, the building blocks of life.

ATMOSPHERE
Pluto's very thin atmosphere freezes and falls to the dwarf planet's surface as Pluto moves toward its aphelion.

98%
Nitrogen

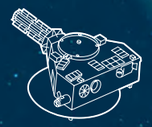
2%
Methane
With some traces of carbon monoxide



CRUST
The crust of this dwarf planet is made of methane and water frozen on the surface.

CORE
The core is made of iron, nickel, and silicates.

MANTLE
The mantle is a layer of frozen water.



NEW HORIZONS MISSION
The first space probe to be sent to Pluto was launched on January 19, 2006. It is to reach the dwarf planet in July 2015 and achieve the first flyby of Pluto and Charon.

A PECULIAR ORBIT

Pluto's orbit is noticeably elliptical, and it is tilted 17° from the plane of the planets' orbits. The distance between Pluto and the Sun varies from 2,500,000,000 to 4,300,000,000 miles (4,000,000,000 to 7,000,000,000 km). During each 248-year orbit, Pluto orbits closer to the Sun than Neptune for nearly 20 years. Although Pluto appears to cross paths with Neptune, it is impossible for them to collide.

6,387
terrestrial days is the time Pluto takes to complete one rotation.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

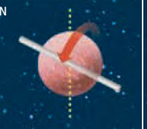
ESSENTIAL DATA

Average distance from the Sun	3,700,000,000 miles (5,900,000,000 km)
Solar orbit (Plutonian year)	247.9 years
Equatorial diameter	1,400 miles (2,247 km)
Orbital speed 3 miles per second	(4.8 km/s)
Mass*	0.002
Gravity*	0.067
Density	1.2 ounces per cubic inch (2.05 g/cu cm)
Average temperature	-380° F (-230° C)
Atmosphere	Very thin
Moons	3

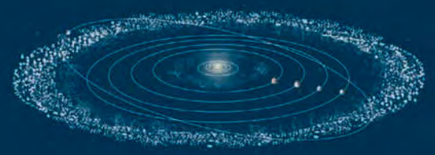
* In both cases, Earth = 1

AXIS INCLINATION

122°
One rotation lasts 6.387 Earth days.



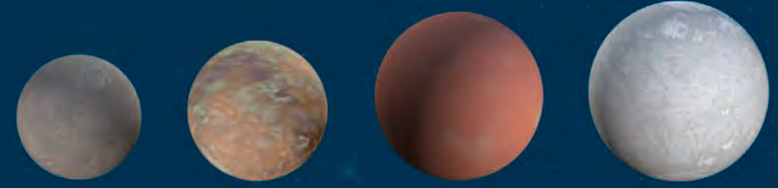
Distant Worlds



Farther even than Neptune, the eighth planet, we find frozen bodies smaller than the Earth's Moon—the more than 100,000 objects forming the Kuiper belt, the frozen boundary of our solar system. Recently astronomers of the International Astronomical Union decided to reclassify Pluto as a dwarf planet because of its size and eccentric orbit. Periodic comets (comets that appear at regular intervals) originate in the Kuiper belt. Nonperiodic comets, on the other hand, come from the Oort cloud, a gigantic sphere surrounding the entire solar system.

Comparable Sizes

The discovery of Quaoar in 2002 allowed scientists to find the link they had long looked for between the Kuiper belt and the origin of the solar system. Quaoar's almost circular orbit helped prove that some objects both belong to the Kuiper belt and orbit the Sun. At the official meeting of the International Astronomical Union, on August 24, 2006, Pluto was reclassified from a planet to a dwarf planet. For the time being, any further objects discovered in the Kuiper belt will be classified in the same category.



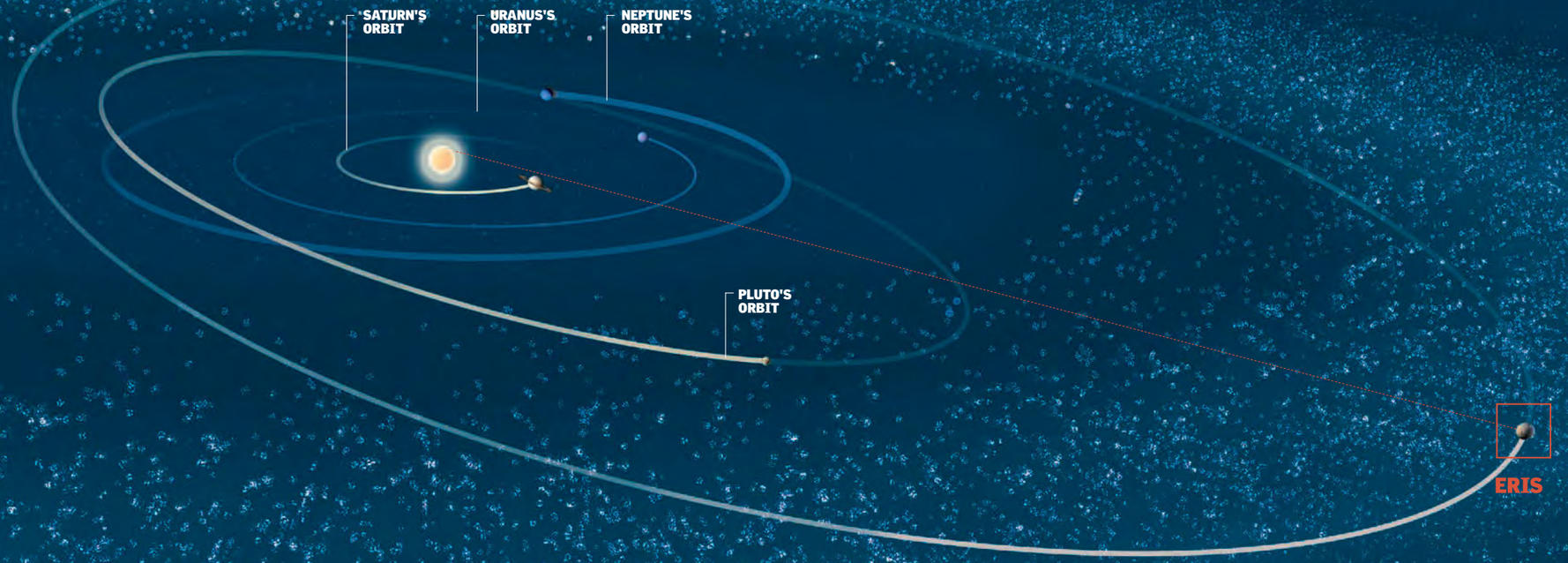
QUAOAR has a diameter of 810 miles (1,300 km).

SEDNA Its diameter is estimated at 1,000 miles (1,600 km).

PLUTO possesses a diameter of 1,400 miles (2,300 km).

ERIS Larger than Pluto, its diameter is about 1,900 miles (3,000 km).

200 OR MORE, POSSIBLE EXTRASOLAR PLANETS HAVE BEEN DETECTED.



Kuiper Belt

Extending outward from the orbit of Neptune are many frozen worlds similar in some ways to planets but much smaller. They are located in the Kuiper belt, the frozen boundary of our solar system. So far, almost a thousand objects have been cataloged, including Quaoar, which has a diameter of 810 miles (1,300 km). The Kuiper belt, estimated to contain more than 100,000 bodies of ice and rock larger than 60 miles (100 km) in diameter (including Pluto), spreads out in the shape of a wide ring. Many of the comets that approach the Sun come from the Kuiper belt.

1,410 miles (2,274 km) is the diameter of Pluto—750 miles (1,200 km) smaller than the Earth's Moon. Because of its size and orbit, Pluto is considered a dwarf planet instead of a planet.

THE FARTHEST ONE

Eris is 97 astronomical units (9,040,000,000 miles [14,550,000,000 km]) from the Sun, making it the most distant object observed in the solar system. This dwarf planet follows an oval, eccentric orbit that takes 560 years to complete. The dwarf planet measures about 1,900 miles (3,000 km) in diameter, and traces of methane ice have been detected on its surface.

Construction Debris: Asteroids and Meteorites

Ever since the formation of the solar system, the melting, collision, and rupture of various materials played an essential role in the formation of the planets. Remnants of this process remain in the form of rock debris, which serves as witnesses to the formation of the solar system. These objects are also associated with episodes that influenced subsequent evolutionary processes on Earth. They are a possible cause of the mass extinction of dinosaurs more than 60 million years ago.

Extraterrestrial

One of the main goals of scientist who study meteorites is to understand their nature. Meteoric material holds extraterrestrial solids and gases. Scientific tests have confirmed that some meteorites are from the Moon or Mars, but most meteorites are associated with asteroids. The samples obtained from meteorites are analyzed and classified by their composition.

TYPES OF METEORITES

STONY
meteorites contain silicate minerals. They are subdivided into chondrites and achondrites.

IRON
meteorites contain a high percentage of iron and nickel compounds. They are created in the rupture of asteroids.

MESOSIDERITES
contain similar quantities of iron, nickel, and silicates.

A HUGE METEORITE STRIKES

A meteorite is an object from space that does not completely vaporize as it penetrates the Earth's atmosphere. Larger meteorites can form a crater when they strike the Earth. Shown is the impact of an exceptionally large meteorite, such as the one that many scientists believed might have led to the extinction of dinosaurs and many other species about 65 million years ago.

1. EXPLOSION
The friction created as a meteorite falls through the air increases its temperature. This is how an ignition process is started.

7 miles per second (12 km/s) **IMPACT VELOCITY**

43 miles per second (70 km/s)

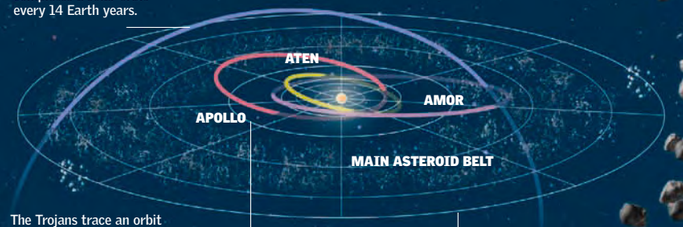
2. DIVISION
The fragmentation of a meteorite causes a visual effect called a shooting star.

3. IMPACT
The collision of the meteorite compresses and excavates the ground, leaving a crater.

Asteroids

Also called minor planets, they are the millions of rock and metal fragments of various shapes and sizes that orbit the Sun. They are mostly located in a belt between the orbits of Mars and Jupiter, but a few, such as those that belong to the Amor, Apollo, and Aten asteroid groups, orbit closer to Earth.

HIDALGO
completes a solar orbit every 14 Earth years.



The Trojans trace an orbit similar to Jupiter's, one group in front of the planet and another behind it.

TYPES OF ASTEROIDS

Despite a great variety in size and shape, three types of minor planets, or asteroids, are known. Classified by their composition, they are grouped as siliceous, carbonaceous, and metallic.

IDA
An asteroid 35 miles (56 km) long, its surface is marked by collisions with other bodies.

Ferrous-type rocks dominate its composition.

15%
The percentage of the total mass of the asteroids compared with the mass of the Moon

Tighten Your Belt

More than a million asteroids at least a mile in diameter are distributed in the main asteroid belt. Ceres was the first asteroid discovered (in 1801). It is the largest known asteroid, with a diameter of 580 miles (932 km).

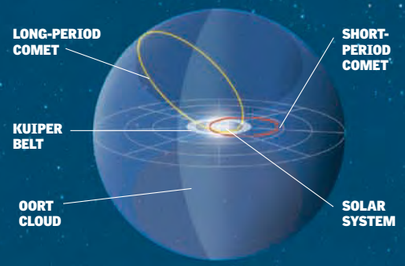
KIRKWOOD
The Kirkwood gaps are the open areas in the main asteroid belt that are devoid of asteroids.

Those with a Tail

Comets are small, deformed objects a few miles in diameter that are normally frozen and dark. Made of dust, rock, gases, and organic molecules rich in carbon, comets are usually found in orbits beyond that of Neptune in the Kuiper belt or in the Oort cloud. Occasionally a comet, such as Halley's comet, veers toward the interior of the solar system, where its ice is heated and sublimates, forming a head and long, spectacular tails of gases and dust.

Types of Comets

Comets with short periods have orbits around the Sun that are shorter than 200 years. Those with a period of more than 200 years travel tens or hundreds of times farther from the Sun than Pluto.



Periodic comets

Comets that leave their original orbits and approach the Sun generally settle into new trajectories. Halley's comet, for example, completes its elongated orbit in 76 years.

HEAD
Formed by the nucleus and the coma. The front part is called the impact front.

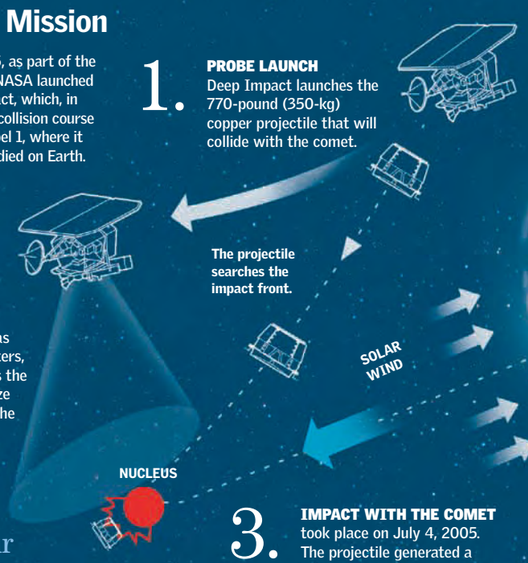
COMA
Envelops the nucleus. It is formed by the gases and dust that it releases.

NUCLEUS
Frozen water, methane, carbon dioxide, ammonia, rock, and dust

Deep Impact Mission

On January 12, 2005, as part of the Discovery program, NASA launched the space probe Deep Impact, which, in turn, sent a projectile on a collision course toward the comet 9P/Tempel 1, where it obtained samples to be studied on Earth.

1. PROBE LAUNCH
Deep Impact launches the 770-pound (350-kg) copper projectile that will collide with the comet.



2. IN POSITION
By means of infrared cameras and spectrometers, the ship follows the comet to analyze the impact on the nucleus.

3. IMPACT WITH THE COMET
took place on July 4, 2005. The projectile generated a crater the size of a football field and seven stories deep.

22,370 miles per hour (36,000 km/h)
VELOCITY OF THE COMET IMPACT

PREVIOUS MISSIONS

NASA has sent other unmanned missions to comets. The first was the international craft ISEE-3/ICE. Launched in 1978, its mission ended after crossing the tail of the Giacobini-Zinner comet in September 1985.

GIOTTO
Launched in 1986, it passed the nucleus of Halley's comet at a distance of 310 miles (500 km) in 1992.

DEEP SPACE
The NASA spacecraft approached the comet Borrelly in 2001.

STARDUST
In 2004, it took samples of the comet Wild 2 and sent them to Earth.

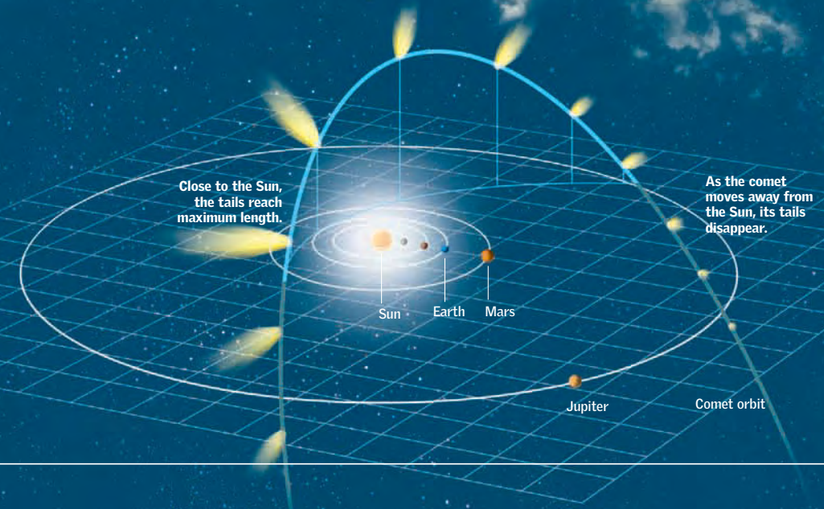
THE HEAD
The head of a comet can measure 62,000 miles (100,000 km) or more in diameter.

ION TAIL
The trail of suspended gases generates a low-intensity, luminous region with a bluish color. The gas molecules lose an electron and therefore have an electrical charge.

DUST TAIL
The suspended dust particles trail behind the comet, reflecting sunlight and making the luminous tail visible.

FORMATION OF THE TAIL AND HEAD

Because of the effects of solar radiation and the solar wind, gases and dust are released from an accelerating comet. The dust particles tend to form a curving trail, which is less sensitive to the pressure of the solar wind. As the comet leaves the confines of the solar system, its tails coincide once more, but they disappear as the nucleus cools down and ceases releasing gases.



The Earth and the Moon

AERIAL VIEW OF THE EARTH
In this partial image of the Earth, we can see Bora-Bora, an island that forms part of the Leeward Islands, located in French Polynesia.

THE BLUE PLANET 68-69
JOURNEY TO THE CENTER OF THE EARTH 70-71
ONCE UPON A TIME 72-73
MOVEMENTS AND COORDINATES 74-75
THE MOON AND TIDES 76-77
ECLIPSES 78-79

In the beginning, the Earth was an incandescent mass that slowly began to cool, allowing the continents to emerge and acquire their current form. Although many drastic changes took place during these early eras, our blue planet has still not stopped changing. It must be recognized that life on Earth would be impossible without the presence of the atmosphere—the colorless, odorless, invisible layer of gases that surrounds us, giving us air to breathe and protecting us from the Sun's harmful radiation. Although the atmosphere is approximately 435 miles (700 km) thick, it has no clear boundary and fades into space until it finally disappears. ●

The Blue Planet

The Earth is known as the blue planet because of the color of the oceans that cover two thirds of its surface. This planet, the third planet from the Sun, is the only one where the right conditions exist to sustain life, something that makes the Earth special. It has liquid water in abundance, a mild temperature, and an atmosphere that protects it from objects that fall from outer space. The atmosphere also filters solar radiation thanks to its ozone layer. Slightly flattened at its poles and wider at its equator, the Earth takes 24 hours to revolve once on its axis.

The Phenomenon of Life

Water, in liquid form, makes it possible for life to exist on the Earth, the only planet where temperatures vary from 32° F to 212° F (0° C to 100° C), allowing water to exist as a liquid. The Earth's average distance from the Sun, along with certain other factors, allowed life to develop 3.8 billion years ago.

70%

of the Earth's surface is water. From space, the planet looks blue.

-7.6° F
(-60° C)

ONLY ICE
Mars is so far from the Sun that all its water is frozen.

32° to 212° F
(0° to 100° C)

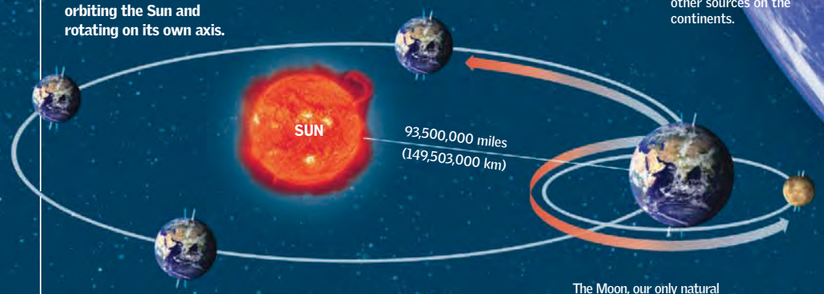
3 STATES
On the Earth, water is found in all three of its possible states.

Above 212° F
(100° C)

ONLY STEAM
On Mercury or Venus, which are very close to the Sun, water would evaporate.

EARTH MOVEMENTS

The Earth moves, orbiting the Sun and rotating on its own axis.



ROTATION: The Earth revolves on its axis in 23 hours and 56 minutes.

REVOLUTION: It takes the Earth 365 days, 5 hours, and 57 minutes to travel once around the Sun.

The Moon, our only natural satellite, is four times smaller than the Earth and takes 27.32 days to orbit the Earth.

1. EVAPORATION
Because of the Sun's energy, the water evaporates, entering the atmosphere from oceans and, to a lesser extent, from lakes, rivers, and other sources on the continents.

2. CONDENSATION
The Earth's winds transport moisture-laden air until weather conditions cause the water vapor to condense into clouds and eventually fall to the ground as rain or other forms of precipitation.

3. PRECIPITATION
The atmosphere loses water through condensation. Gravity causes rain, snow, and hail. Dew and frost directly alter the state of the surface they cover.

23.5°

This is the inclination of the Earth's axis from the vertical. As the Earth orbits the Sun, different regions gradually receive more or less sunlight, causing the four seasons.

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

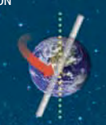
Average distance to the Sun	93 million miles (150 million km)
Revolution around the Sun (Earth year)	365.25 days
Diameter at the equator	7,930 miles (12,756 km)
Orbiting speed	17 miles per second (27.79 km/s.)
Mass*	1
Gravity*	1
Density	3.2 ounces per cubic inch (5.52 g/cu cm)
Average temperature	59° F (15° C)

*In both cases, Earth = 1

AXIS INCLINATION

23.5°

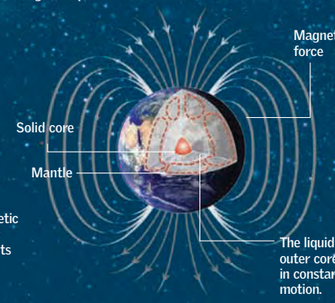
One rotation lasts 23.56 hours.



Magnetism and Gravity

The Earth's magnetic field originates in the planet's outer core, where turbulent currents of molten iron generate both electric and magnetic fields. The orientation of the Earth's magnetism varies over time, causing the magnetic poles to fluctuate.

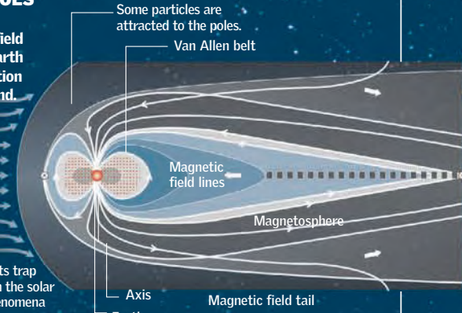
The Earth's core works as a magnet.



The Earth's magnetic field is created by convective currents in its outer core.

WHAT IT DOES

The magnetic field protects the Earth from the radiation of the solar wind.



The Van Allen belts trap the particles from the solar wind, causing phenomena like the auroras.

GRAVITY AND WEIGHT

Weight is the force of the gravity that acts on a body.

24 pounds (11 kg)

ON THE MOON
The Moon has less mass than the Earth and, as a result, less gravity.

154 pounds (70 kg)

ON EARTH
The object is drawn toward the Earth's center.

390 pounds (177 kg)

ON JÚPITER
Jupiter has 300 times more mass than the Earth and therefore more gravity.

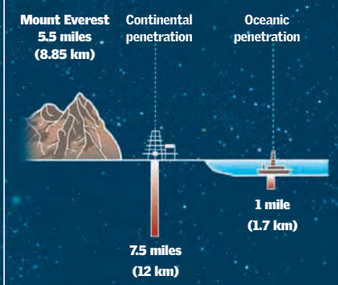
Journey to the Center of the Earth

We live on the Earth, but do we know what we are standing on? The planet is made up of layers of various materials, such as solid and molten rock, which in turn are composed of such elements as iron, nickel, and silicon. Our atmosphere is the layer of gases surrounding our planet. One of these gases, oxygen, does a very special job—it permits life to exist.

Internal Structure

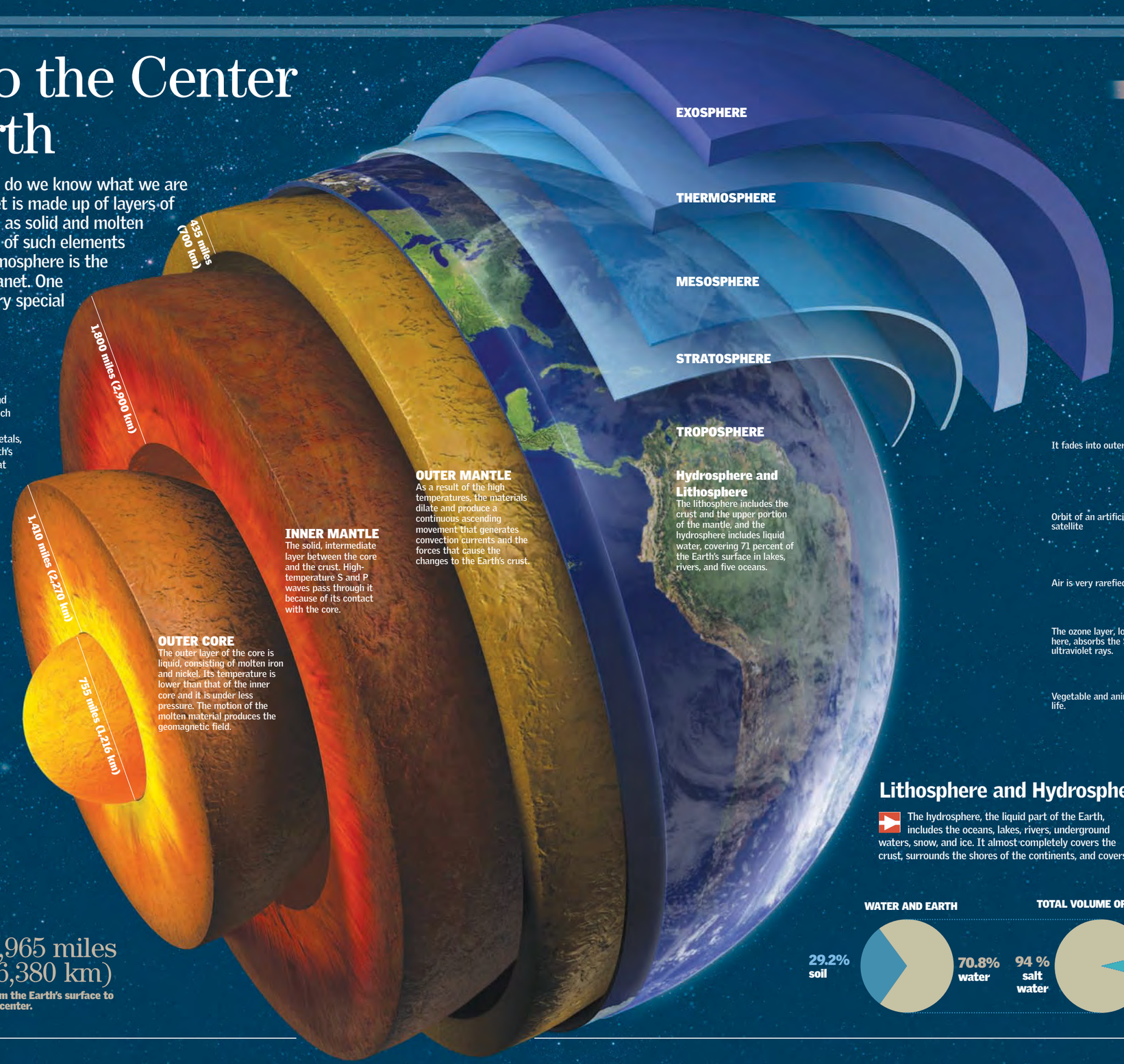
We live on a rocky surface similar to a shell. The rocks we live with are made mostly of oxygen and silicon, but underneath them is the mantle, made of much heavier rocks. The mantle also surrounds the inner and outer cores with a region of constantly boiling liquid metals, creating the convective currents that generate the Earth's magnetic field. The inner core, solid because of the great pressure put upon it, is the densest part of the planet.

HOW FAR HUMANS HAVE GONE



INNER CORE
is made of the same metals as the outer core, but, despite its high temperature, its center is solid because of the enormous pressure that compresses it.

3,965 miles (6,380 km)
from the Earth's surface to its center.



OUTER MANTLE
As a result of the high temperatures, the materials dilate and produce a continuous ascending movement that generates convection currents and the forces that cause the changes to the Earth's crust.

INNER MANTLE
The solid, intermediate layer between the core and the crust. High-temperature S and P waves pass through it because of its contact with the core.

OUTER CORE
The outer layer of the core is liquid, consisting of molten iron and nickel. Its temperature is lower than that of the inner core and it is under less pressure. The motion of the molten material produces the geomagnetic field.

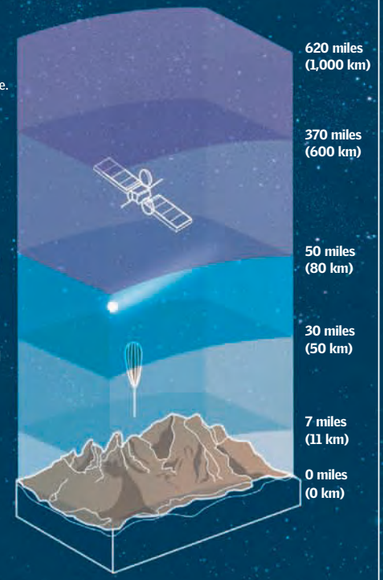
Hydrosphere and Lithosphere
The lithosphere includes the crust and the upper portion of the mantle, and the hydrosphere includes liquid water, covering 71 percent of the Earth's surface in lakes, rivers, and five oceans.

WITH ATMOSPHERE
The sunlight filters into the atmosphere. Winds distribute the heat, cooling the tropics and warming the poles.

WITHOUT ATMOSPHERE
Direct solar radiation. Differences in temperature between the equator and the poles would be far more pronounced.

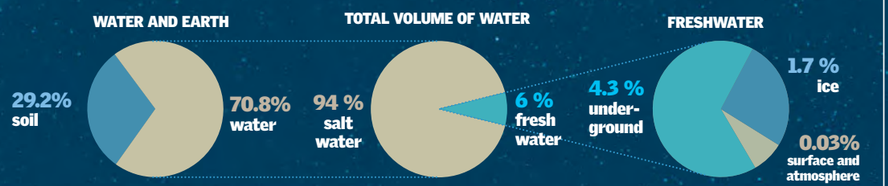
Above the Surface

The existence of life on our planet would be impossible without the atmosphere that provides the air we breathe and the water we drink; it also protects us from the Sun's harmful radiation, while simultaneously maintaining mild temperatures by retaining the Sun's warmth. The atmosphere is about 435 miles thick (700 km) but lacks defined limits.



Lithosphere and Hydrosphere

The hydrosphere, the liquid part of the Earth, includes the oceans, lakes, rivers, underground waters, snow, and ice. It almost completely covers the crust, surrounds the shores of the continents, and covers 71 percent of the Earth's surface. The lithosphere is a superficial, elastic region that is 4 to 7 miles (6 to 11 km) thick under the oceans and up to 43 miles (70 km) thick under mountain ranges.



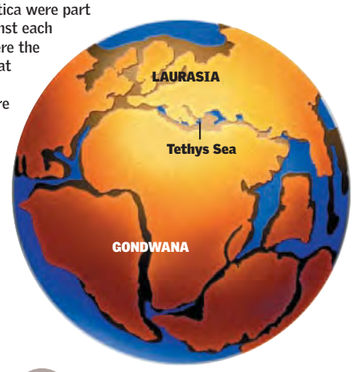
Once Upon a Time

The Earth probably formed from material in the solar nebula—the cloud of gas and dust that led to the formation of the Sun. This material gradually grew into a larger and larger body that became a red-hot ball of rock and metal. Later the rocky crust formed, its surface cooling enough to allow the continents to appear. Even later the oceans arrived, as well as the tiny organisms that released oxygen into the atmosphere. Although much of this gas was initially consumed in chemical reactions, over time, it allowed the development of multicellular organisms and an explosion of life that took place at the start of the Paleozoic Era, 542 million years ago.

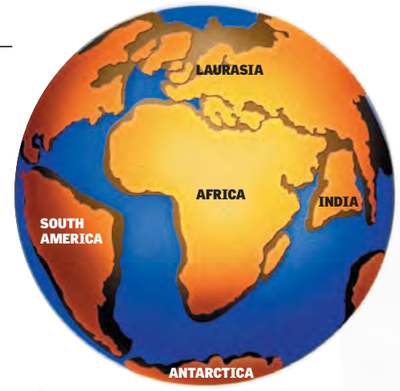
Continental Drift

We live on the continents, which are part of movable plates that drift across the Earth's surface at the rate a fingernail grows. 250 million years ago, India, Africa, Australia, and Antarctica were part of the same continent. When tectonic plates rub against each other, land and oceanic crust earthquakes occur. Where the plates separate, a rift forms. The mid-ocean ridges that run beneath the oceans are formed by lava that emerges from the rifts between tectonic plates. Where plates collide, a process called subduction takes place, in which the rocks of the oceanic floor are drawn under the continent and melt, reemerging in the form of volcanoes.

1 290 MILLION YEARS AGO
The supercontinent called Pangea formed. An immense ocean called Panthalassa surrounded it.

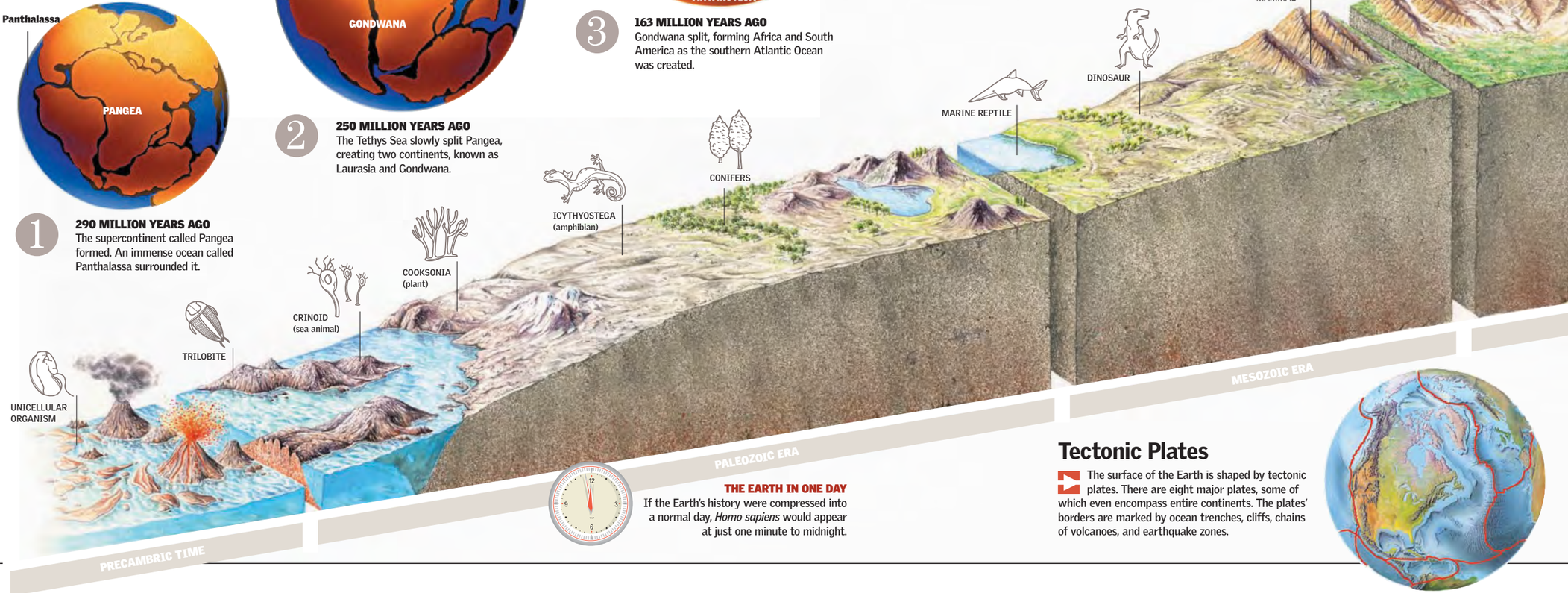


2 250 MILLION YEARS AGO
The Tethys Sea slowly split Pangea, creating two continents, known as Laurasia and Gondwana.



3 163 MILLION YEARS AGO
Gondwana split, forming Africa and South America as the southern Atlantic Ocean was created.

4 60 MILLION YEARS AGO
The northern Atlantic Ocean slowly separated, completing the formation of Europe and North Africa.



THE EARTH IN ONE DAY
If the Earth's history were compressed into a normal day, *Homo sapiens* would appear at just one minute to midnight.

Origin of the Earth

The Earth was formed 4.6 billion years ago from a cloud of dust and gas. In the beginning, it was a molten, constantly active, mass. As time passed, the Earth began to cool, and the atmosphere began to clear as rain fell, creating the oceans.

A Ball of fire The Earth was created from small particles that coalesced in the solar nebula.

B The planet cooled The atmosphere was created as the planet cooled and began to emit gases and steam.

C The crust forms Lava poured across the surface of the Earth. As it cooled, it formed the Earth's crust.

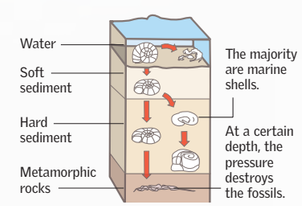
D Water appeared on the Earth 3.9 billion years ago. Water-rich Earth is the only planet in the solar system known to have life.

Chronology

Geology is the study of rocks in the Earth's crust. It divides the Earth's history into different eras, periods, and epochs lasting millions of years. Geology also helps us catalog the processes of evolution—changes in generations as species adapt to their environment and their competitors.

Through the study of fossils—remains of creatures buried in the Earth's various sedimentary layers and consequently at different times in the past–geology helps us trace the timeline of evolutionary history.

FOSSILS
are remains of living beings preserved in the rocks as a record of the Earth's history.



Tectonic Plates

The surface of the Earth is shaped by tectonic plates. There are eight major plates, some of which even encompass entire continents. The plates' borders are marked by ocean trenches, cliffs, chains of volcanoes, and earthquake zones.

Movements and Coordinates

Yes, it moves. The Earth rotates on its axis while simultaneously orbiting the Sun. The natural phenomena of night and day, seasons, and years are caused by these movements. To track the passage of time, calendars, clocks, and time zones were invented. Time zones are divided by meridians and assigned a reference hour according to their location. When traveling east, an hour is added with each time zone. An hour is subtracted during west-bound travel.

The Earth's Movements

Night and day, summer and winter, new year and old year result from the Earth's various movements during its orbit of the Sun. The most important motions are the Earth's daily rotation from west to east on its own axis and its revolution around the Sun. (The Earth follows an elliptical orbit that has the Sun at one of the foci of the ellipse, so the distance to the Sun varies slightly over the course of a year.)

ROTATION
1 DAY
The Earth revolves once on its axis in 23 hours and 56 minutes. We see this as day and night.

REVOLUTION
1 YEAR
The Earth's orbit around the Sun lasts 365 days, 5 hours, and 57 minutes.

NUTATION
18.6 YEARS
is a sort of nod made by the Earth, causing the displacement of the geographic poles by nine arc seconds.

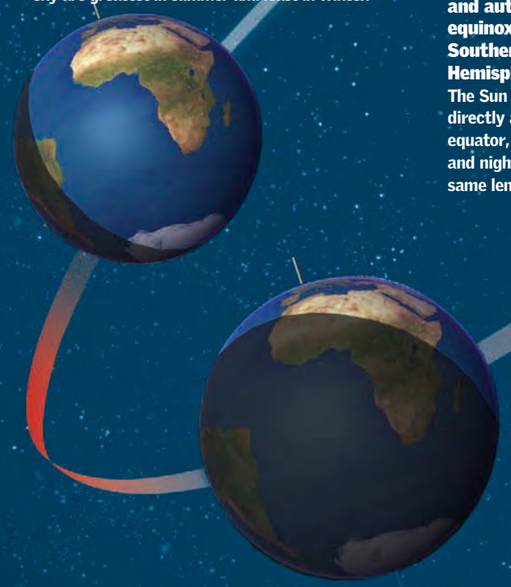
PRECESSION
25,800 YEARS
A slow turning of the direction of the Earth's axis (similar to that of a top), caused by the Earth's nonspherical shape and the gravitational forces of the Sun and the Moon

Equinox and Solstice

Every year, around June 21, the Northern Hemisphere reaches its maximum inclination toward the Sun (a phenomenon referred to as the summer solstice in the Northern Hemisphere and the winter solstice in the Southern Hemisphere). The North Pole receives sunlight all day, while the South Pole is covered in darkness. Between one solstice and another the equinoxes appear, which is when the axis of the Earth points toward the Sun and the periods of daylight and darkness are the same all over our planet.

June 20 or 21

Summer solstice in the Northern Hemisphere and winter solstice in the Southern Hemisphere.
Solstices exist because of the tilt of the Earth's axis. The length of the day and the height of the Sun in the sky are greatest in summer and least in winter.



March 20 or 21

Spring equinox in the Northern Hemisphere and autumn equinox in the Southern Hemisphere.
The Sun passes directly above the equator, and day and night have the same length.

September 21 or 22

Autumn equinox in the Northern Hemisphere and spring equinox in the Southern Hemisphere.
The Sun passes directly above the equator, and day and night have the same length.

MEASUREMENT OF TIME
Months and days are charted by calendars and clocks, but the measurement of these units of time is neither a cultural nor an arbitrary construct. Instead, it is derived from the natural movements of the Earth.

PERIHELION
The point where the orbiting Earth most closely approaches the Sun (91 million miles [147 million km])

23.5º
TILT OF THE EARTH'S AXIS

93
MILLION MILES
(149 MILLION KM)

THE EARTH'S ORBIT
About 365 days

1 day

THE DAYS
Period of time it takes the Earth to rotate on its axis

About 30 days

THE MONTHS
Each period of time, between 28 and 31 days, into which a year is divided

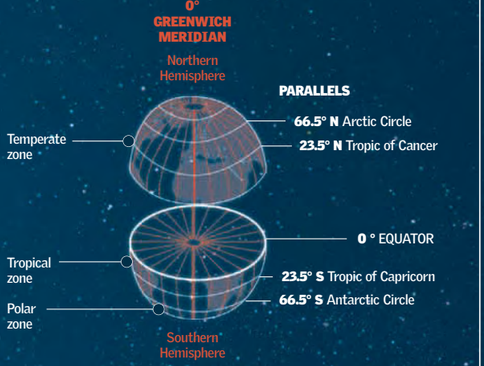
December 21 or 22

Winter solstice in the Northern Hemisphere and summer solstice in the Southern Hemisphere.
Solstices exist because of the tilt of the Earth's axis. The length of the day and the height of the Sun in the sky are greatest in summer and least in winter.

APHELION
The point in the Earth's orbit where it is farthest from the Sun (94 million miles [152 million km]). This occurs at the beginning of July.

Geographic Coordinates

Thanks to the grid formed by the lines of latitude and longitude, the position of any object on the Earth's surface can be easily located by using the intersection of the Earth's equator and the Greenwich meridian (longitude 0°) as a reference point. This intersection marks the midpoint between the Earth's poles.

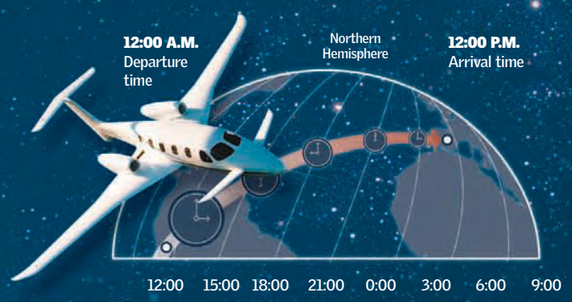


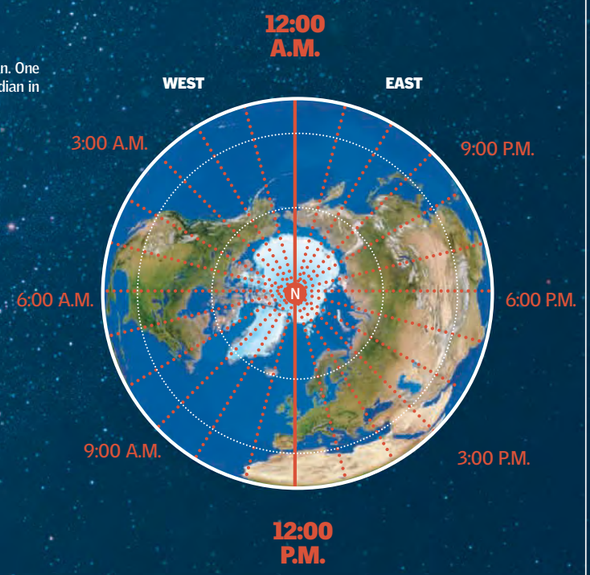
Time Zones

The Earth is divided into 24 areas, or time zones, each one of which corresponds to an hour assigned according to the Coordinated Universal Time (UTC), using the Greenwich, England, meridian as the base meridian. One hour is added when crossing the meridian in an easterly direction, and one hour is subtracted when traveling west.

JET LAG

The human body's biological clock responds to the rhythms of light and dark based on the passage of night and day. Long air flights east or west interrupt and disorient the body's clock, causing a disorder known as jet lag. It can cause fatigue, irritability, nausea, headaches, and difficulty sleeping at night.





The Moon and Tides

Romance and terror, mystery and superstition–all these emotions are responses to the Moon, the Earth's one natural satellite, which always hides one of its two faces. However, whatever symbolic meanings are attributed to the Moon, its gravitational pull has a concrete effect on the Earth—it is a cause of the tides. Depending on the distance of the Moon from the Earth, the gravitational pull exerted by the Moon varies in strength and so can high tides and low tides. To reach full height, tides need large open areas of ocean. For this reason, tides in closed or small bodies of water are much lower.

THE MOON'S MOVEMENTS

As the Moon orbits the Earth, it revolves on its own axis in such a way that it always shows the Earth the same side.

LUNAR MONTH
It takes 29.53 days to complete its phases.

SIDEREAL MONTH
It takes 27.32 days to orbit the Earth.

HIDDEN FACE
Invisible from the Earth, this side of the Moon was a mystery until 1959, when the Russian probe Luna 3 managed to photograph the hidden zone. Because of the greater thickness of the Moon's crust on this side, it has fewer seas.

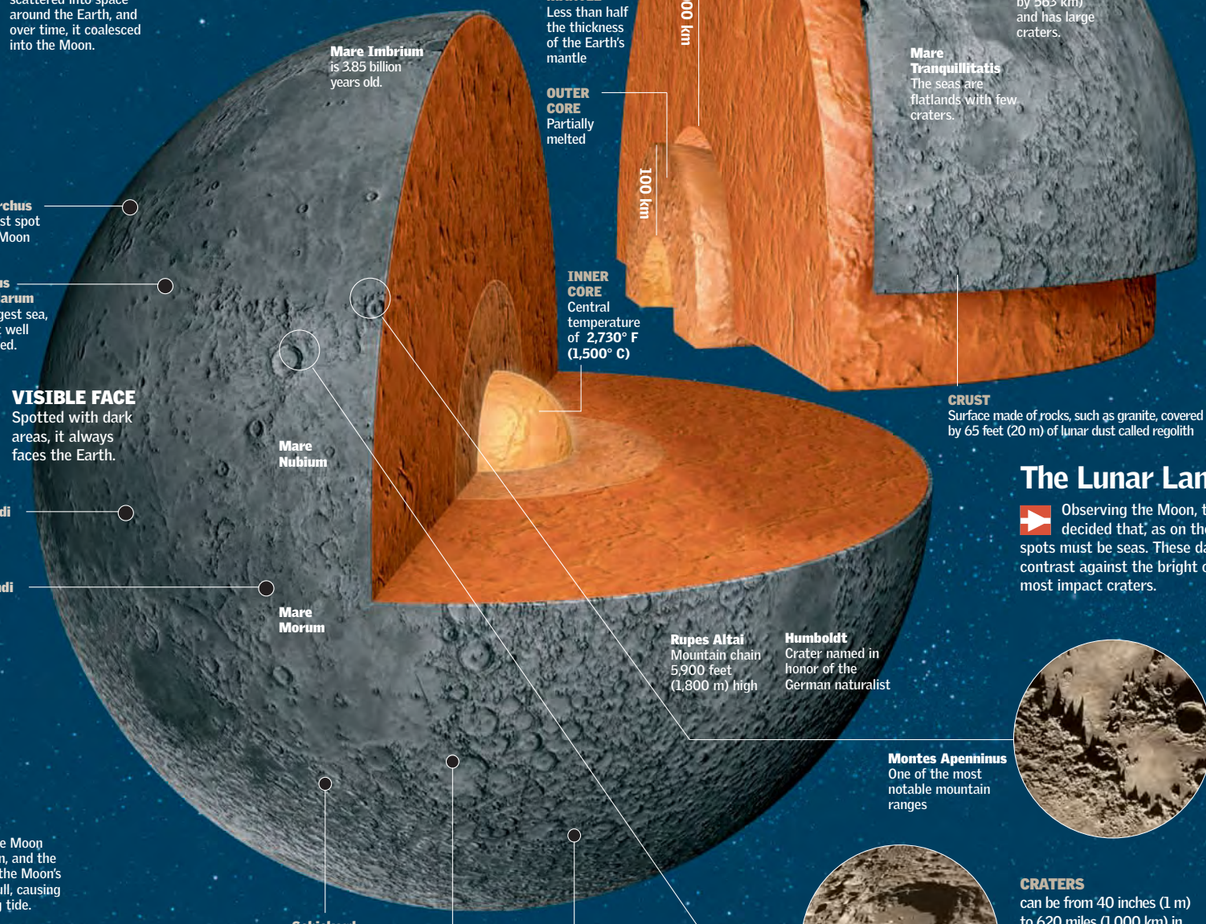
ORIGIN OF THE MOON
The most widely accepted theory of the Moon's origin suggests that an object the size of Mars collided with the Earth during its formation.

The ejected material scattered into space around the Earth, and over time, it coalesced into the Moon.

INNER STRUCTURE

Various seismic analyses of the Moon suggest that its core is solid or semisolid.

2,160 miles (3,476 km)
The diameter of the Moon is one fourth of the Earth's.



Aristarchus
Brightest spot on the Moon

Oceanus Procellarum
The largest sea, it is not well preserved.

VISIBLE FACE
Spotted with dark areas, it always faces the Earth.

Grimaldi

Gassendi

Mare Nubium

Mare Morum

Rupes Altai
Mountain chain 5,900 feet (1,800 m) high

Humboldt
Crater named in honor of the German naturalist

Montes Apenninus
One of the most notable mountain ranges

Schickard

Tycho
100 million years old

Maguinus

Copernicus
60 miles (93 mi) in diameter

CHARACTERISTICS

CONVENTIONAL PLANET SYMBOL

ESSENTIAL DATA

Average distance from the Earth	226,400 miles (364,400 km)
Revolution around the Earth	27.3 days
Diameter at the equator	2,160 miles (3,476 km)
Orbiting speed	0.6 miles per second (1.02 km/s)
Mass*	0,01
Gravity*	0,17
Density	2 ounces per cubic inch (3.34 g/cu cm)
Temperature	302° F (150° C) (day) -148° F (-100° C) (night)
Volume*	0.02

*Earth = 1

AXIS INCLINATION

5.14°

One rotation lasts 27.32 Earth days.

The Tides

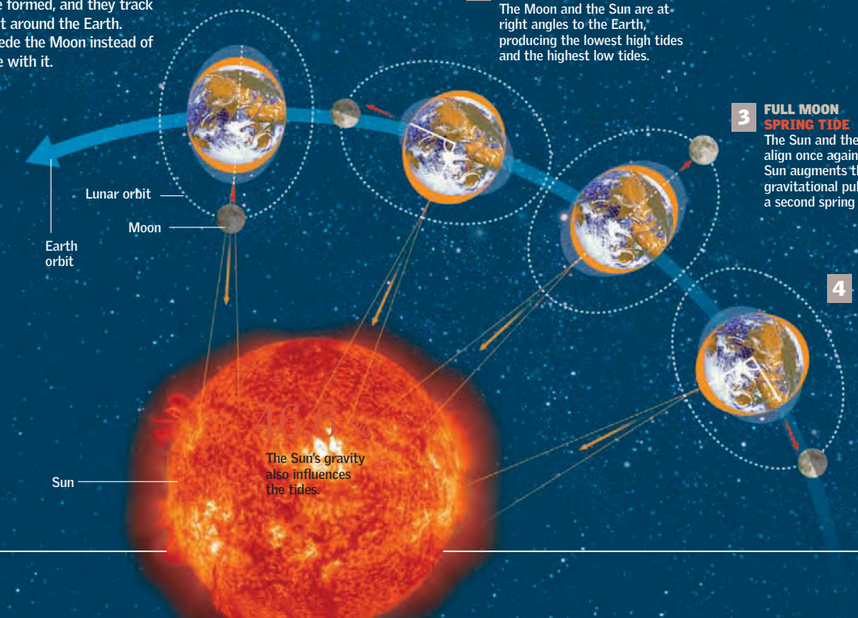
The water on the side of the Earth closest to the Moon feels the Moon's gravitational pull most intensely, and vice versa. Two tides are formed, and they track the Moon in its orbit around the Earth. However, they precede the Moon instead of being directly in line with it.

1 NEW MOON
SPRING TIDE
When the Sun and the Moon are aligned, the highest high tides and lowest low tides are produced.

2 FIRST QUARTER
NEAP TIDE
The Moon and the Sun are at right angles to the Earth, producing the lowest high tides and the highest low tides.

3 FULL MOON
SPRING TIDE
The Sun and the Moon align once again, and the Sun augments the Moon's gravitational pull, causing a second spring tide.

4 THIRD QUARTER
NEAP TIDE
The Moon and the Sun again form a right angle, causing a second neap tide.



The Lunar Landscape

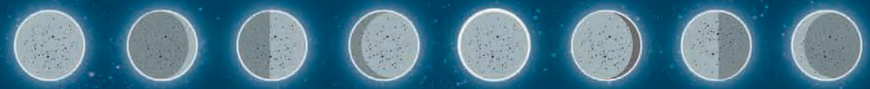
Observing the Moon, the ancient astronomers decided that, as on the Earth, its plainly visible dark spots must be seas. These dark regions of the Moon contrast against the bright ones, the highlands with the most impact craters.

MOUNTAIN RANGES
When a meteorite strikes the lunar surface, a mountain range forms from the material ejected during the cratering process.

CRATERS
can be from 40 inches (1 m) to 620 miles (1,000 km) in diameter and are formed by meteorites that strike the Moon's surface with incredible force.

SEAS
cover almost 16 percent of the Moon's surface and were formed by flowing lava. Today the Moon has no volcanic activity.

THE PHASES OF THE MOON



Unique
The Moon is the Earth's only natural satellite.

Eclipses

Typically four times a year, during the full or new moon, the centers of the Moon, the Sun, and the Earth become aligned, causing one of the most marvelous celestial phenomena: an eclipse. At these times, the Moon either passes in front of the Sun or passes through the Earth's shadow. The Sun—even during an eclipse—is not safe to look at directly, since it can cause irreparable damage to the eyes, such as burns on the retina. Special high-quality filters or indirect viewing by projecting the Sun's image on a sheet of paper are some of the ways in which this celestial wonder can be watched. Solar eclipses provide, in addition, a good opportunity for astronomers to conduct scientific research.

TOTAL LUNAR ECLIPSE, SEEN FROM THE EARTH

The orange color comes from sunlight that has been refracted and colored by the Earth's atmosphere.

ANNUAL ECLIPSE OF THE SUN, SEEN FROM THE EARTH

Lunar Eclipse

When the Earth passes directly between the full Moon and the Sun, a lunar eclipse (which could be total, partial, or penumbral) occurs. Without the Earth's atmosphere, during each lunar eclipse, the Moon would become completely invisible (something that never happens). The totally eclipsed Moon's characteristic reddish color is caused by light refracted by the Earth's atmosphere. During a partial eclipse, on the other hand, part of the Moon falls in the shadow cone, while the rest is in the penumbra, the outermost, palest part. It is not dangerous to look at a lunar eclipse directly.

ALIGNMENT

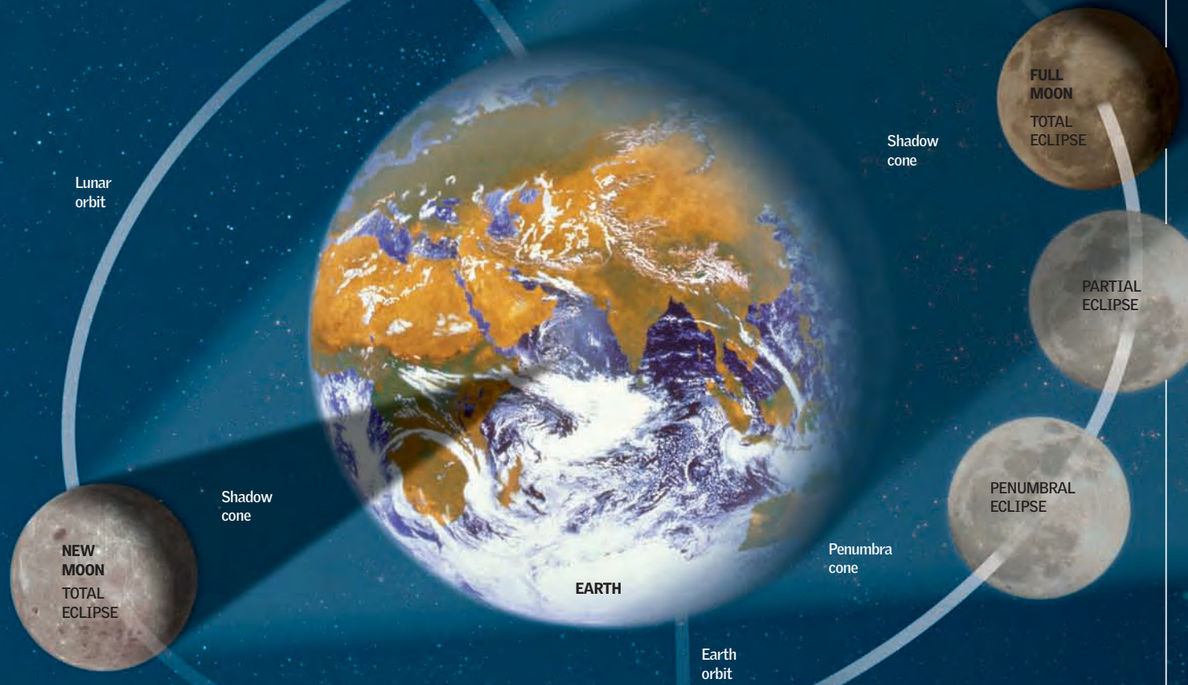
During an eclipse, the Moon is not completely black-but appears reddish.

TYPES OF ECLIPSES

TOTAL
The Moon is completely in the shadow cone.

PARTIAL
The Moon is only partially inside the shadow cone.

PENUMBRAL
The Moon is in the penumbral cone.



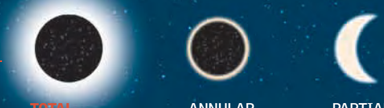
Solar Eclipse

Solar eclipses occur when the Moon passes directly between the Sun and the Earth, casting a shadow along a path on the Earth's surface. The central cone of the shadow is called the umbra, and the area of partial shadow around it is called the penumbra. Viewers in the regions where the umbra falls on the Earth's surface see the Moon's disk completely obscure the Sun—a total solar eclipse. Those watching from the surrounding areas that are located in the penumbra see the Moon's disk cover only part of the Sun—a partial solar eclipse.

ALIGNMENT

During a solar eclipse, astronomers take advantage of the blocked view of the Sun in order to use devices designed to study the Sun's atmosphere.

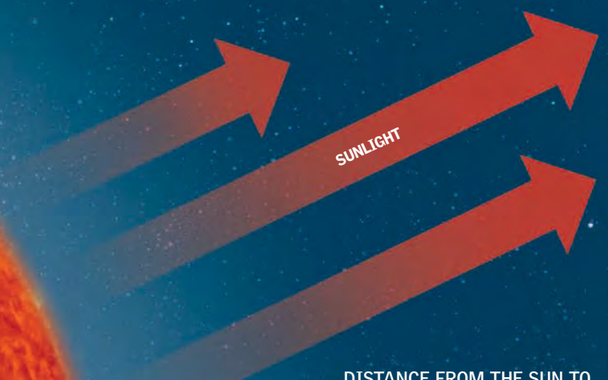
TYPES OF ECLIPSES



TOTAL
The Moon is between the Sun and the Earth and creates a cone-shaped shadow.

ANNULAR
The Sun appears larger than the Moon, and it remains visible around it.

PARTIAL
The Moon does not cover the Sun completely, so the Sun appears as a crescent.



SUN'S APPARENT SIZE

400 times larger than the Moon

DISTANCE FROM THE SUN TO THE EARTH

400 times greater than the distance from the Earth to the Moon

THE ECLIPSE CYCLE

Eclipses repeat every 223 lunations—18 years and 11 days. These are called Saros periods.

ECLIPSES IN A YEAR			ECLIPSES IN A SAROS		
2	7	4	41	29	70
Minimum	Maximum	Average	of the Sun	of the Moon	Total

OBSERVATION FROM EARTH

A black, polymer filter, with an optical density of 5.0, produces a clear orange image of the Sun.

Prevents retinal burns

SOLAR ECLIPSES
are different for each local observer.

MAXIMUM DURATION
8 minutes

LUNAR ECLIPSES
are the same for all observers.

MAXIMUM DURATION
100 minutes

ECLIPSES IN 2006 AND BEYOND

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
OF THE SUN	3/29 Total	9/22 Total	3/19 Partial	9/11 Partial	2/07 Total	1/26 Total	7/22 Total	1/15 Total	7/11 Total	1/4 Partial	11/25 Partial	5/20 Annular	11/13 Annular	5/10 Annular	11/3 Hybrid	4/29 Annular	10/23 Partial	3/20 Total	9/13 Partial
OF THE MOON	3/14 Partial	9/07 Partial	3/03 Total	8/28 Total	2/21 Total	8/16 Partial	2/9 Partial	7/7 Partial	6/26 Partial	12/21 Total	6/15 Total	12/10 Total	6/4 Partial	12/28 Partial	4/25 Partial	10/18 Partial	4/15 Total	10/08 Total	4/4 Total	9/28 Total

Observing the Universe

STONEHENGE
Located in Wiltshire (England), it was built in several phases over some 600 years—between 2200 and 1600 BC. The placement of most of its large stones has a relationship to the Moon and the Sun.

ASTRONOMICAL THEORIES 82-83
SPRINKLED WITH STARS 84-85
CELESTIAL CARTOGRAPHY 86-87
FROM THE HOME GARDEN 88-89
A FOUR-EYED GIANT 90-91

Astronomy was born out of humankind's need to measure time and seasons, marking the best times to plant. In ancient times, the study of the stars was mixed with superstition and ritual. The megalithic monument Stonehenge, found in southern England, is an example of this. Today, thanks to advances in new technologies, such as the giant telescopes installed in various locations around the planet, we have discovered many new things about the universe. The VLT (Very Large Telescope), astronomy's new monster telescope located in Chile, is part of an attempt to find planets beyond the solar system, because many astronomers suspect that life is not exclusive to the Earth. ●

Astronomical Theories

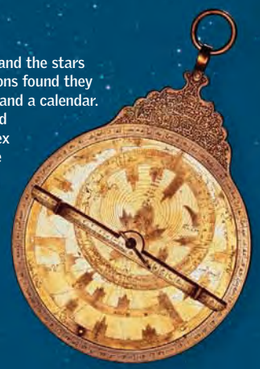
For a long time, it was believed that the Earth was stationary. The Sun, the Moon, and the planets were thought to orbit it. To study the sky and calculate its movements, people began to build instruments, such as the astrolabe, armillary sphere, and telescope. The telescope revolutionized the conception of the universe. Instead of the Earth being at the center of the universe, it was suggested that the Earth and other planets travel around the Sun. The Roman Catholic Church opposed the idea and, for a time, persecuted dissident astronomers and banned their theories.

Geocentric Model

Before telescopes, binoculars, and modern observatories existed, little was known about the Earth. Many believed that the Earth was fixed and that the Sun, the Moon, and the five known planets orbited it in circles. This geocentric model was promoted by the Egyptian astronomer Claudius Ptolemy, who in the 2nd century AD compiled the astronomical ideas of the ancient Greek astronomers (in particular, those of Aristotle, who had proposed the Earth as the center of the universe, with the celestial objects revolving around it). Although other ancient astronomers, such as Aristarchus of Samus, proposed that the Earth was round and rotated around the Sun, Aristotle's ideas were accepted as true for 16 centuries, and at times Aristotle's ideas were defended and preserved by the Roman Catholic Church.

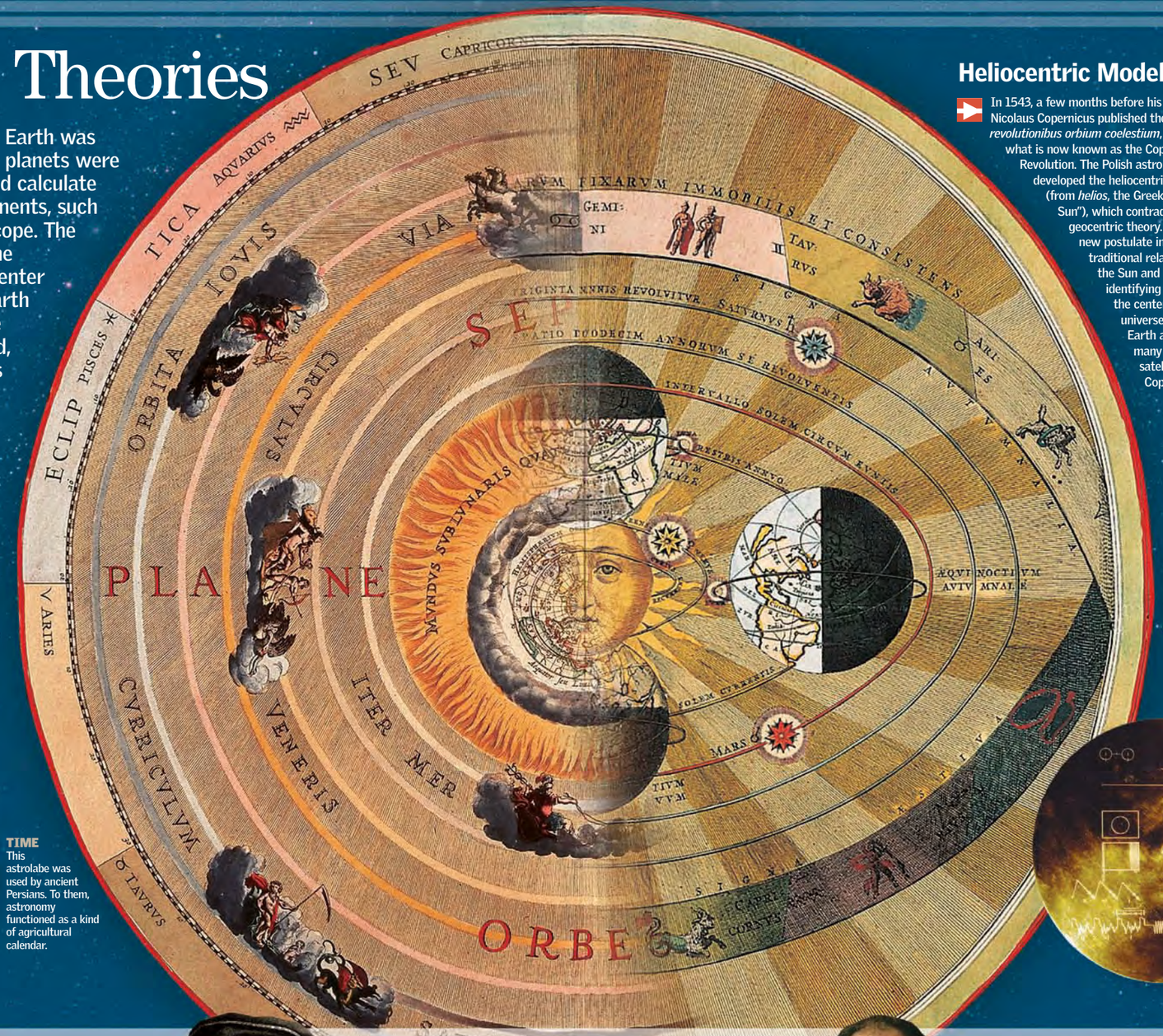
MEASUREMENTS

Noticing that the Sun, the Moon, and the stars moved in cycles, ancient civilizations found they could use the sky as both a clock and a calendar. However, ancient astronomers had difficulties performing the complex calculations needed to predict the positions of stars accurately enough to create a truly precise calendar. A useful tool developed to perform this task was the astrolabe. Its engraved plates reproduce the celestial sphere in two dimensions, allowing the elevations of the celestial bodies to be measured.



TIME

This astrolabe was used by ancient Persians. To them, astronomy functioned as a kind of agricultural calendar.

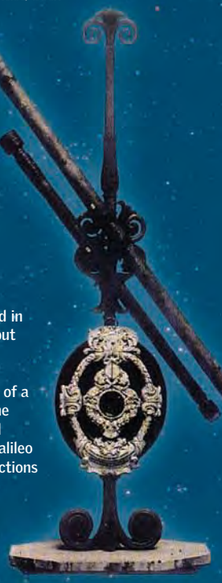


Heliocentric Model

In 1543, a few months before his death, Nicolaus Copernicus published the book *De revolutionibus orbium coelestium*, inaugurating what is now known as the Copernican Revolution. The Polish astronomer developed the heliocentric theory (from *helios*, the Greek word for "the Sun"), which contradicted the geocentric theory. Copernicus's new postulate inverted the traditional relationship of the Sun and the Earth, identifying the Sun as the center of the universe and the Earth as one of many solar satellites. Copernicus argued that spheres moved in endless, circular orbits. Since the universe and all the celestial bodies were thought to be spherical, he argued that their movements must also be circular and uniform (the Ptolemaic system considered the planets' circuits to be irregular). Copernicus reasoned that, since the movements of the planets appeared to be irregular, the Earth must not be the center of the universe. These discoveries were contrary to the views promulgated by the Roman Catholic Church. In fact, both Roman Catholics and Protestants suppressed any writings advocating these beliefs. When Galileo Galilei was brought to trial by the Roman Catholic Church for advocating the Copernican theory, he was forced to renounce his views.

GALILEO'S TELESCOPE

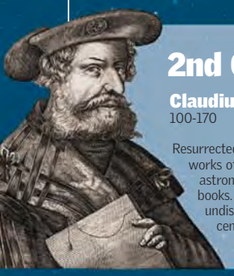
The telescope is thought to have been invented in 1609 by the Dutch optician Hans Lippershey but had no real scientific application until Galileo Galilei improved and adapted it to observe celestial bodies. Galileo's first telescope, made of a leather tube covered by a lens at each end (one lens convex and the other concave), magnified objects up to 30 times. Using the telescope, Galileo discovered that the Sun's surface had imperfections (sunspots), that the Moon had mountains and craters, and that there were four moons, or satellites, that traveled around Jupiter.



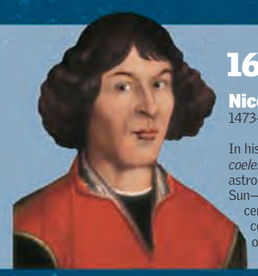
THE TRAVELERS

After many years and great advancements in technology, scientists decided that space observation conducted only from the Earth's surface was insufficient. In 1959, the first space probe was launched, an automatic vehicle that flew to the Moon and photographed its hidden face. The space probes Voyager 1 and 2 explored the planets Jupiter, Saturn, Uranus, and Neptune, a milestone in space exploration. In 2005, Voyager 1 reached the region called Termination Shock, the frontier of the solar system, representing the farthest region explored by humanity. Both probes carried with them golden discs, named Sounds of Earth, containing sounds and images portraying the diversity of life on Earth.

COSMIC CHARACTERS

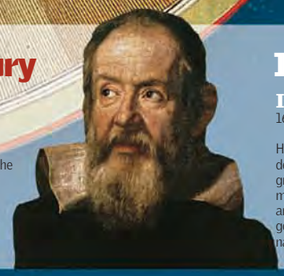


2nd Century
Claudius Ptolemy
100-170
Resurrected and compiled the works of great Greek astronomers into two books. His postulates held undisputed authority for centuries.

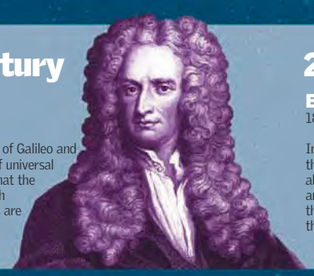


16th Century
Nicolaus Copernicus
1473-1543
In his *De revolutionibus orbium coelestium*, the Polish astronomer postulated that the Sun—not the Earth—was the center of the universe. This concept is the foundation of our own astronomy..

17th Century
Johannes Kepler
1571-1630
The German astronomer, believer in Copernicus's heliocentric model, formulated three famous laws of planetary movement, which encouraged Galileo to publish his research.



17th Century
Galileo Galilei
1564-1642
Built the first telescope, a primitive device with which he discovered sunspots, four of Jupiter's moons, the phases of Venus, and craters on the Moon's surface.



17th Century
Isaac Newton
1642-1727
He built upon the ideas of Galileo and developed the theory of universal gravitation, asserting that the movements of the Earth and the celestial bodies are governed by the same natural laws.

20th Century
Edwin Hubble
1889-1953
In 1929, he began to investigate the expansion of the galaxies, allowing scientists to obtain an idea of the true scale of the universe as well as refine the big bang theory.

Sprinkled with Stars

Constellations are groups of stars thought to represent different animals, mythological characters, and other figures. Constellations were invented by ancient civilizations to serve as reference points in the Earth's sky. There are 88 of these collections of stars. Although each star in a constellation appears related to the others, it is actually very far from them. Not all the constellations are visible at the same time from any one place on the Earth.

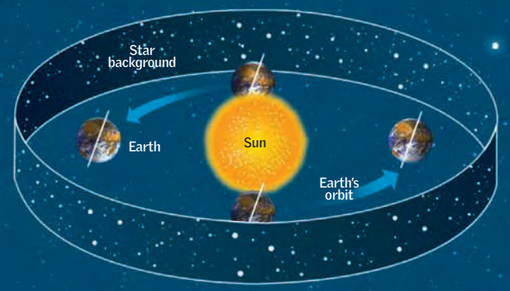
ORIGIN

The history of western culture's constellations begins with the first astronomical observations made by ancient Mesopotamian peoples. Because we inherited the constellations from Greco-Roman culture, most of the constellations are named after figures in classical mythology. All of the earliest constellations were named by the 16th century. Constellations discovered more recently bear names drawn from science or technology or from exotic fauna discovered in various places across the globe.

88
constellations

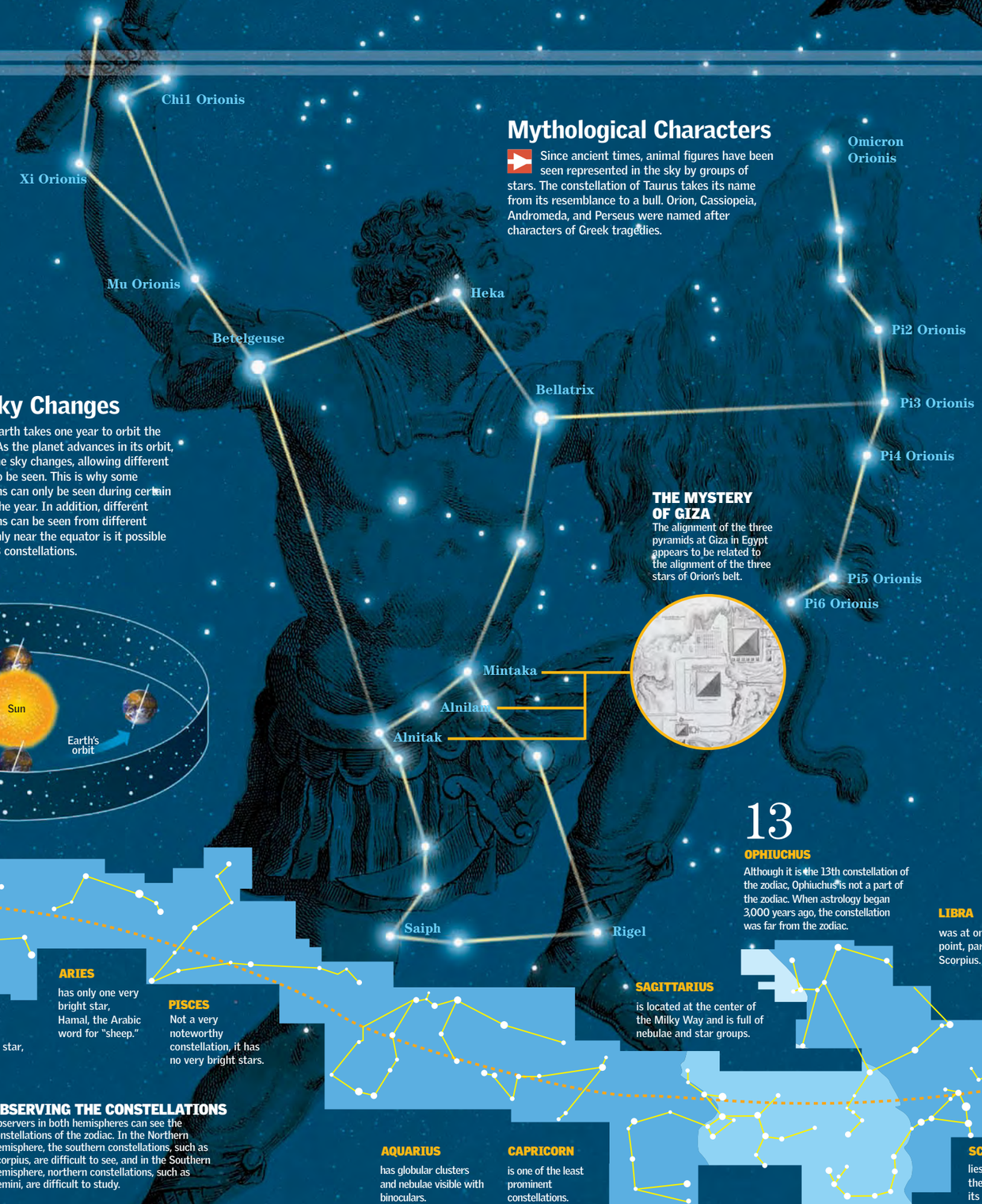
The Sky Changes

The Earth takes one year to orbit the Sun. As the planet advances in its orbit, the nighttime sky changes, allowing different parts of it to be seen. This is why some constellations can only be seen during certain seasons of the year. In addition, different constellations can be seen from different latitudes. Only near the equator is it possible to see all 88 constellations.



Mythological Characters

Since ancient times, animal figures have been seen represented in the sky by groups of stars. The constellation of Taurus takes its name from its resemblance to a bull. Orion, Cassiopeia, Andromeda, and Perseus were named after characters of Greek tragedies.



THE MYSTERY OF GIZA

The alignment of the three pyramids at Giza in Egypt appears to be related to the alignment of the three stars of Orion's belt.

Different Cultures

In antiquity, each culture recognized certain constellations that other civilizations did not. The Chinese see smaller, more detailed patterns in the stars, allowing for more precise positional information. Various cultures also tend to use varied names for the same constellation. Scorpius is recognized by the people of Mesopotamia, Greece, Rome, Mesoamerica, and Oceania—under different names.

SCORPIUS

In Greco-Roman mythology, Orion and Scorpius are closely linked. Orion is the giant, handsome, seductive hunter.

URSA MAJOR

The bear represented by this constellation is unusual because of its long tail. The constellations' shapes rarely agree perfectly with their namesakes.

THE CENTAUR

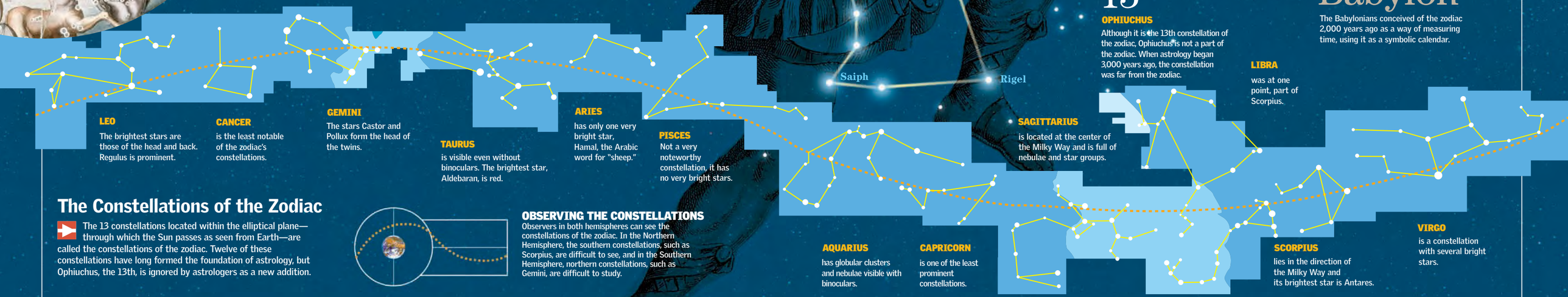
is a creature from Greek mythology, half man and half horse. The centaur accompanied Orion during his quest to recover his sight.

The Constellations of the Zodiac

The 13 constellations located within the elliptical plane—through which the Sun passes as seen from Earth—are called the constellations of the zodiac. Twelve of these constellations have long formed the foundation of astrology, but Ophiuchus, the 13th, is ignored by astrologers as a new addition.

OBSERVING THE CONSTELLATIONS

Observers in both hemispheres can see the constellations of the zodiac. In the Northern Hemisphere, the southern constellations, such as Scorpius, are difficult to see, and in the Southern Hemisphere, northern constellations, such as Gemini, are difficult to study.



LEO

The brightest stars are those of the head and back. Regulus is prominent.

CANCER

is the least notable of the zodiac's constellations.

GEMINI

The stars Castor and Pollux form the head of the twins.

TAURUS

is visible even without binoculars. The brightest star, Aldebaran, is red.

ARIES

has only one very bright star, Hamal, the Arabic word for "sheep."

PISCES

Not a very noteworthy constellation, it has no very bright stars.

AQUARIUS

has globular clusters and nebulae visible with binoculars.

CAPRICORN

is one of the least prominent constellations.

SAGITTARIUS

is located at the center of the Milky Way and is full of nebulae and star groups.

SCORPIUS

lies in the direction of the Milky Way and its brightest star is Antares.

LIBRA

was at one point, part of Scorpius.

VIRGO

is a constellation with several bright stars.

13

OPHIUCHUS

Although it is the 13th constellation of the zodiac, Ophiuchus is not a part of the zodiac. When astrology began 3,000 years ago, the constellation was far from the zodiac.

Babylon

The Babylonians conceived of the zodiac 2,000 years ago as a way of measuring time, using it as a symbolic calendar.

Celestial Cartography

As on the Earth, so in heaven. Just as terrestrial maps help us find locations on the surface of the planet, star charts use a similar coordinate system to indicate various celestial bodies and locations. Planispheres, or star wheels, are based on the idea of a celestial sphere (an imaginary globe on which the stars appear to lie and that surrounds the planet). Two common types are polar and bimonthly star maps.

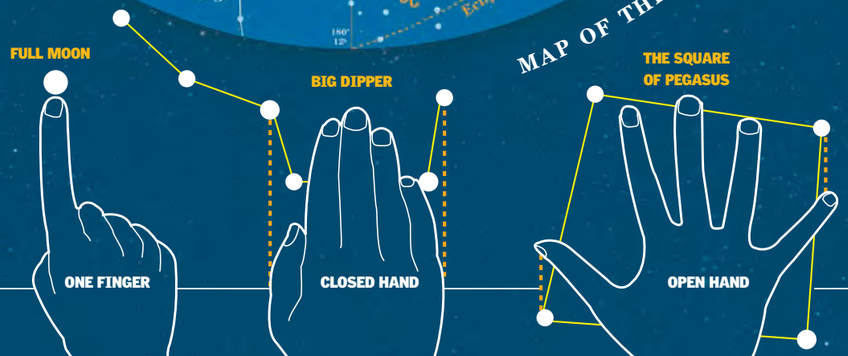
THE CELESTIAL SPHERE

The celestial sphere is imagined to extend around the Earth and forms the basis for modern star cartography. The sphere is divided into a network of lines and coordinates corresponding to those used on the Earth, allowing an observer to locate constellations on the sphere. The celestial equator is a projection of the Earth's equator, the north and south celestial poles align with the axis of the Earth, and the elliptic coincides with the path along which the Sun appears to move.

MAP OF THE STELLAR NORTH POLE

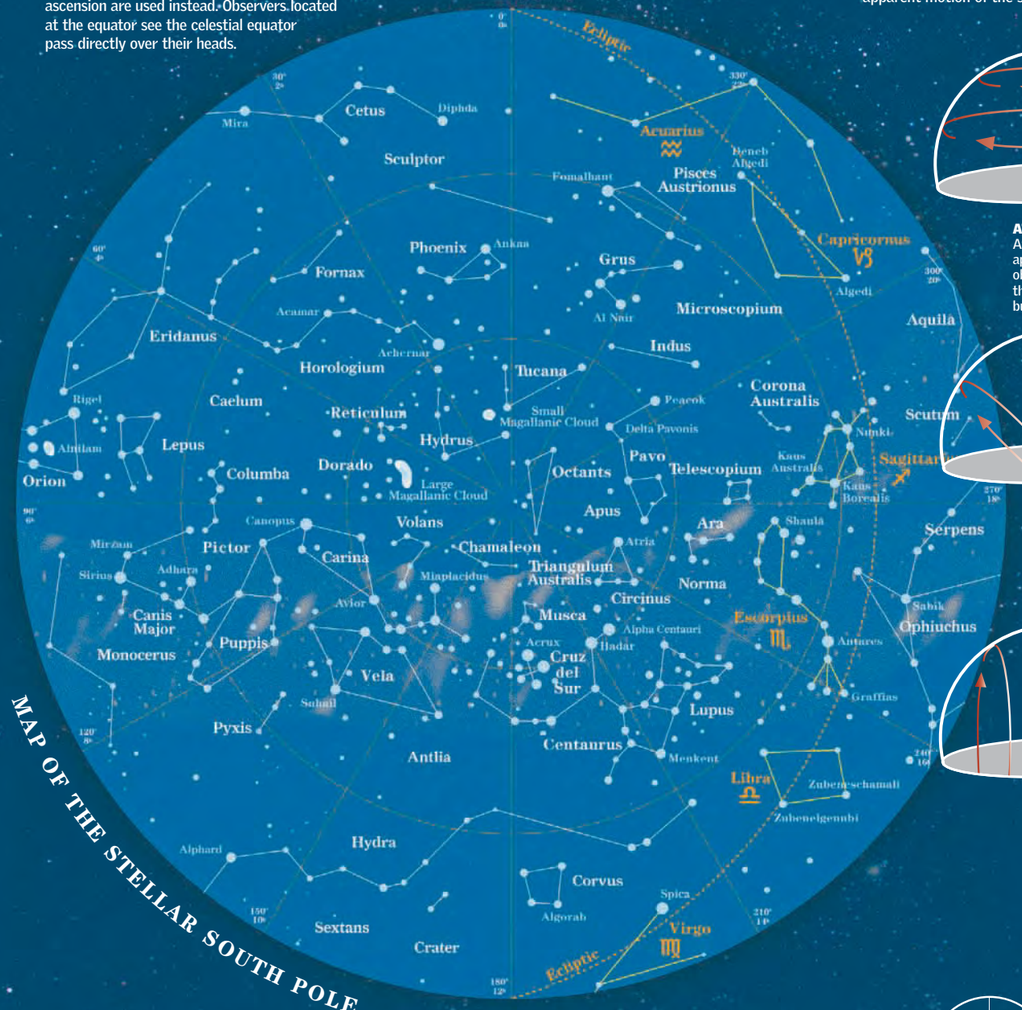
Measuring Distances

Once a star or constellation has been located in the sky, hands and arms can serve as simple measuring tools. A single extended finger, shown in the first illustration, can form a one-degree angle from the observer's line of sight and is useful for measuring short distances between stars. The closed palm of the hand forms a 10° angle, and the open hand measures 20°.



HOW TO READ A MAP OF THE SKY

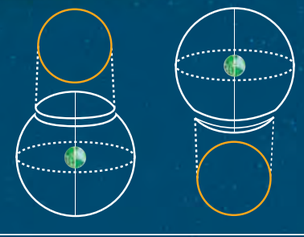
Astronomers divide the celestial sphere into sections, allowing them to study the sky in detailed, systematic ways. These maps can show a particular region observed from a certain place at a certain time, or they can merely concentrate on a specific location. To specify the position of a point on the surface of the Earth, the geographic coordinates called latitude and longitude are used. With the celestial sphere, declination and right ascension are used instead. Observers located at the equator see the celestial equator pass directly over their heads.



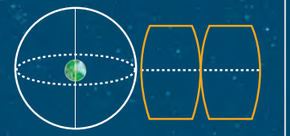
MAP OF THE STELLAR SOUTH POLE

Different Types of Charts

Throughout the year, different constellations are visible because the Earth moves along its orbit. As the Earth's place in its orbit changes, the night side of the planet faces different regions of space. To compensate for this shifting perspective, there are various kinds of planispheres: north and south polar maps and bimonthly equatorial maps.



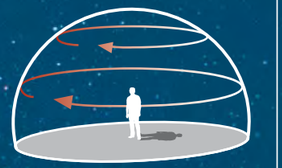
POLAR
The celestial sphere is generally divided into two polar maps: north and south.



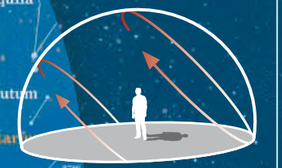
EQUATORIAL
Six bimonthly maps depict all 88 constellations, which can be seen over the course of the year.

Stellar Movements

The visible regions of the celestial sphere and the ways in which stars move through the sky depend upon the observer's latitude. As an observer moves north or south, the visible portion of the celestial sphere will change. The elevation of the north or south celestial pole above the horizon determines the apparent motion of the stars in the sky.



AT THE POLES
At the North Pole, the stars appear to rotate around the observer's head. The effect is the same at the South Pole but in the opposite direction.



IN MIDDLE LATITUDES
some stars can be seen all year long, but others are only visible during certain months.

AT THE EQUATOR
stars can be seen throughout the year, rising in the east and setting in the west.

From the Home Garden

Stargazing is not difficult. After learning to locate celestial objects, many people find the hobby very gratifying. With the aid of a star map, you can recognize galaxies, nebulae, star clusters, planets, and other objects. Some of these treasures of the universe are visible with the unaided eye, but others require binoculars or even more sophisticated telescopes. Familiarity with the night sky is useful in many ways.

Basics

Before stepping out to observe the night sky, make sure you have everything you need. If you collect all your supplies beforehand, you will avoid having to expose your eyes to bright light once they have adjusted to darkness. In addition to binoculars, star maps, and a notebook, you should bring warm clothes, a comfortable seat, and something to drink.

Planisphere

Compass

Flashlight with red cellophane

How to Look at the Moon

Under various degrees of magnification, the Moon and stars take on different appearances. In some cases, you can make observations of the Moon with the unaided eye as well as with binoculars or a telescope.

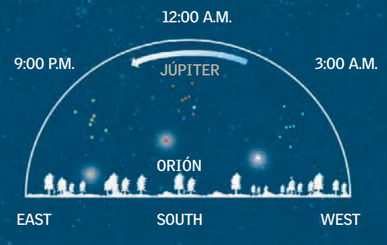
Normal view

View with binoculars

View with telescope

THE MOTION OF CONSTELLATIONS

The Earth's rotation makes the planets and stars appear to move through the nighttime sky in a general east-to-west direction. When the southern constellation Orion, visible from November through March, is viewed from the Northern Hemisphere, it appears to move from left to right.



Observable Objects

The sky is a very busy place. Not only are there stars and planets, but there are also satellites, airplanes, comets, and meteorites. Fortunately all become recognizable by their appearance as well as their movement.

VENUS
can generally be seen above the horizon at dusk or dawn.

SHOOTING STARS
Very short flashes of light lasting only a fraction of a second

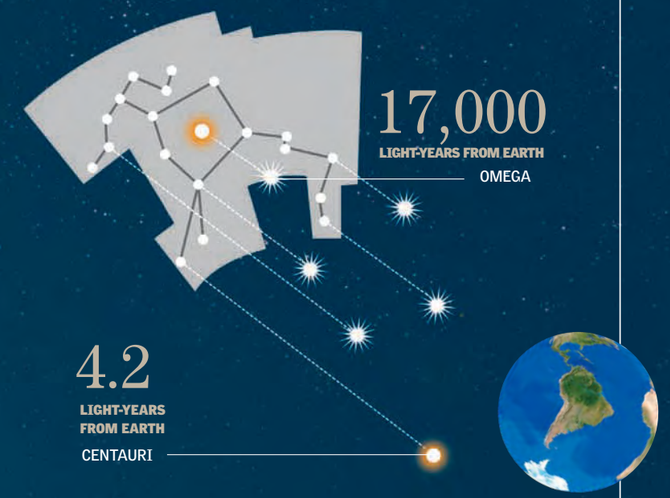
SATELLITES
The bigger ones are brighter than some stars. Some take a while to cross the sky.

MOON
The illuminated face of the Moon can always be seen at some time during the night, at least partially, except around the new moon.

COMETS
visible to the naked eye appear every one to two years and are visible for weeks or even months.

Flat Perspective

A constellation is a group of stars that, when viewed from a certain angle, seem to assume a specific shape. However, these stars that seem closely joined together are, in fact, separated by great distances.



Measurement methods

A planisphere is a circular star chart that is used to locate celestial bodies in the celestial sphere. To identify a particular object, your own arms and body can be used to measure its direction and altitude in relation to the horizon.

MEASUREMENT OF ELEVATION

Starting at the horizon, extend one of your arms until it is perpendicular to the other.

To measure a 45° angle, move your arm halfway up from the horizon.

MEASURING DIRECTION

The planisphere indicates the principal direction of a star. Place the arms at 90°, using north or south as the base.

A star to the southwest could be located with your arms at 45°. Combine the directional angles with your hand measurements for elevation.

A Four-Eyed Giant

The Paranal Observatory, one of the most advanced in the world, is located in the region of Antofagasta, Chile. It uses four identical telescopes to obtain enough light-gathering power that it could see the flame of a candle on the surface of the Moon. This sophisticated collection of digital cameras, reflecting mirrors, and other instruments is mounted in the interior of four metallic structures weighing hundreds of tons. The Very Large Telescope (VLT) is operated by a scientific consortium drawn from eight European countries. One of their stated objectives is to discover new worlds orbiting other stars.

CLIMATIC CONDITIONS
Cerro Paranal is located in the driest part of the Atacama desert, where the conditions for astronomical observation are extraordinarily favorable. It is an 8,645-foot- (2,635-m-) tall mountain that has about 350 cloudless nights a year.

10.9 (750)
LB PER SQ IN (MBAR)
Air pressure

0.06 (0.96)
LB PER CU FT (KG/M3)
Air density

18–77° (-8–25°)
FAHRENHEIT (CELSIUS)
Average temperature

5 to 20
PERCENT
Humidity

DOME
Its protective cover perceives changes in the weather by means of thermal sensors.

3.9-foot- (1.2-m-) diameter secondary mirror

Mechanical structure

Telescope units

ANTU

MELIPAL

KUEYEN

YEPUN

AUXILIARY TELESCOPE (AT)
There are four, each 5.9 feet (1.8 m) in diameter. They assist with interferometry.

Light tunnels for interferometry

Rails to transport the AT

The Telescope

The main feature of the VLT is its revolutionary optical design. By using adaptive and active optics, it achieves resolution similar to that possible from space.

ACTIVE OPTICS

150-piston cell

ADAPTIVE OPTICS

Light enters

Reflected light beam

Uncorrected vision

Curved mirror

Corrected vision

Cerro Paranal Observatory

The ESO's Very Large Telescope is located to the north of the Atacama desert, on Cerro Paranal. Completed in 2006, it has four 26.9-foot- (8.2-m-) wide reflector telescopes capable of observing objects four billion times fainter than those visible to the unaided eye. It also has three 5.9-foot- (1.8-m-) wide movable auxiliary telescopes that are used in conjunction with the larger ones to simulate the light-gathering power of a 52-foot- (16-m-) wide mirror (with the resolution of a 656-foot- [200-m-] long telescope). This is enough to see an astronaut on the Moon. The above technique is called interferometry.

215,000 SQ FT
(20,000 SQ M) TOTAL SURFACE

7,759 FEET
(2,365 M) ABOVE SEA LEVEL

ADAPTIVE OPTICS
To prevent the primary mirror from deforming because of gravitational effects, the VLT has an adaptive optics system that maintains the mirror in optimal shape, with 150 supporting pistons that continually adjust the shape of the mirror.

VLT
ACRONYM FOR
Very Large Telescope

ARMILLARY SPHERE
Invented by Eratosthenes in the year 225 BC, it was used as a teaching aid and became especially popular in the Middle Ages thanks to Danish astronomer Tycho Brahe.

2500–2000 BC
STONEHENGE
Located in Wiltshire, England, it is an observatory temple dating from the Neolithic Period.

435–455 BC
CARACOL
It is located in the ruins of the Mayan city of Chichén Itzá. The structure was used for venerating the Sun, the Moon, and Venus.

1726
JAIPUR
Located in India, it was built by the maharajah Sawai Jai Singh and has a large sextant and a meridional chamber.

1888
LICK
Located on 4,265-foot- (1,300-m-) high Mount Hamilton. It was the first observatory to be located on a mountain.

1897
YERKES
Located in Wisconsin, it contains the largest refracting telescope in the world.

1979
MAUNA KEA
An international complex located in Hawaii, with large British, French-American, and American observatories

Glossary

Annihilation

Total destruction of matter in a burst of energy, as when it encounters antimatter.

Antigravity

Hypothesized force, equal to gravity and diametrically opposed to it.

Antimatter

Matter formed from subatomic particles with shared properties. Its electrical charge is opposite that of normal matter.

Aperture

Diameter of the main mirror of a telescope or eyepiece. The larger the aperture, the more light the device receives.

Aphelion

The point in a celestial body's orbit farthest from the Sun. The Earth reaches aphelion on or about July 4, when it is 95,000,000 miles (152, 600,000 km) from the Sun.

Apogee

The farthest position from the Earth reached by the Moon or any of the artificial satellites that orbit the planet.

Asteroids

Minor bodies of the solar system, formed by rock, metal, or a mixture of both. Most asteroids orbit the Sun between the orbits of Mars and Jupiter. Their size ranges from dozens of feet to hundreds of miles.

Astrolabe

Ancient astronomical instrument for measuring both the positions and the movements of celestial objects.

Astronomy

Science that studies the universe. It is concerned with the physical characteristics, movements, distances, formation, and interactions of galaxies, stars, planets, moons, comets, asteroids, and other celestial bodies.

Atmosphere

Layer of gas retained around a planet by its gravity. It is also the outer layer of matter in a star, where the energy produced in the star's interior is emitted in the form of radiation.

Atom

The smallest part of an element that partakes of all the element's properties. It is generally composed of three subatomic particles: the neutron, the proton, and the electron.

Aurora

Luminous phenomenon, with red and green layers, visible in the skies of the polar regions. The auroras are caused by the collision of solar particles with the Earth's atmosphere.

Austral

Related to the Southern Hemisphere.

Big Bang

Cosmological theory asserting that the universe began to exist as a result of a great explosion that occurred some 14 billion years ago.

Big Crunch

Cosmological theory asserting that the universe would undergo a final, complete collapse if it were to begin to contract.

Black Hole

Celestial body so dense that not even light can escape its gravity.

Black Hole, Stellar-Mass

Black hole produced by the explosion of a massive star as a supernova. Its mass is typically about 10 times that of the Sun.

Black Hole, Supermassive

Black hole located at the center of a galaxy and formed by material that falls into the central region of the galaxy. Its mass can be a billion times that of the Sun.

Carbon

One of the most common elements in the universe, produced by stars. All known life is carbon-based.

Chromosphere

The lowest layer of the Sun's atmosphere. It emits a pinkish-red light that can be seen only when the brighter photosphere is obscured during a total eclipse.

Circumpolar Star

Any star always visible to an observer on the Earth as it rotates about the celestial pole.

Comet

Object made of ice and rock dust. When a comet approaches the Sun, the growing heat causes the ice to evaporate, forming a gaseous head and a tail of dust and gas pointing away from the Sun.

Constellation

Group of stars in the sky. Constellations tend to bear the names of mythological characters or creatures. To astronomers, the constellations demarcate regions of the sky.

Core

In a planet, a solid, high-pressure central mass; in a star, the central region undergoing nuclear fusion; in a galaxy, the innermost light-years.

Corona

Upper atmosphere of the Sun. It is visible as a pearly halo during a total solar eclipse.

Cosmos

Another name for the universe.

Crater

Circular depression formed by the impact of a meteorite on the surface of a natural satellite or a planet.

Crust

Rocky layer of the surface of a planet or natural satellite.

Curvature of Light

Distortion of light rays when passing through regions with strong gravitation.

Decay

Process by which radioactive elements and unstable particles become stable substances. Also the way in which black holes eventually disappear.

Density

Degree of solidity of a body (its mass divided by its volume).

Eclipse

Visual concealment of one celestial body by another. A lunar eclipse occurs when the Moon passes into the Earth's shadow, and a solar eclipse takes place when the Earth passes into the Moon's shadow.

Ecliptic

Imaginary line around the sky along which the Sun moves during the year. The orbits of the Earth and the other planets generally lie along the ecliptic.

Electrical Charge

Property of particles causing them to either attract or repel each other because of electrical forces. Electrical charges are either positive or negative.

Electromagnetic Radiation

Radiation composed of magnetic and electric fields moving at the speed of light. It encompasses radio waves (long wavelengths), visible light, and gamma rays (very short wavelengths).

Element

A basic substance of nature that cannot be diminished without losing its chemical properties. Each element (such as hydrogen, helium, carbon, oxygen) has its own characteristics.

Elliptical Orbit

Orbit shaped like a flattened circle. All orbits are elliptical. A circle is a special form of an ellipse.

Energy

The capacity to do work.

Event Horizon

The edge of a black hole.

Extraterrestrial

Foreign to the Earth.

Force

Something that changes the motion or shape of a body.

Galactic Filament

Structure formed by superclusters of galaxies stretching out through great portions of space. Filaments are the largest structures in the universe and are separated by great voids.

Galaxy

Collection of billions of stars, nebulae, dust, and interstellar gas held together by gravity.

Galaxy Cluster

Group of galaxies linked together by gravity.

Gamma Rays

Form of electromagnetic radiation with greatest energy and shortest wavelength. It is generated by only the most powerful phenomena in the universe, such as supernovae or the fusion of neutron stars.

General Relativity

Theory formulated by Albert Einstein in 1915. In part, it holds that gravity is a natural consequence of the curvature of space-time caused by the presence of a massive body. In general relativity, the phenomena of classical mechanics (such as the orbit of a planet or the fall of an object) are caused by gravity and are represented as inertial movements within space-time.

Gravitational Wave

Waves in space that travel at the speed of light and are produced by the movements of very massive bodies.

Gravity

Attractive force between bodies, such as between the Earth and the Moon.

Greenhouse Effect

Temperature increase caused by gases (such as carbon dioxide and methane) that prevent the surface heat of a planet from escaping into space.

Heliosphere

The region of space around the Sun in which its effects are evident. It extends some 100 astronomical units around the Sun.

Helium

The second most common and second lightest element in the universe. It is a product of the big bang and of nuclear fusion of stars.

Hubble Constant

Number that measures the rate of expansion of the universe. It is expressed in kilometers per second per millions of parsecs. It is currently estimated at 70 km/s/Mpc.

Hydrogen

The most common and lightest element in the universe; the main component of stars and galaxies.

Hypernova

Destruction of a massive star, which emits a wave of gamma rays extending great distances across the universe.

Implosion

Collapse of a body upon itself in response to great external pressure.

Infrared Radiation

Heat radiation, with a wavelength between visible light and radio waves.

Intergalactic Space

Space between galaxies.

Interstellar Space

Space between the stars.

Ionosphere

Region of the Earth's atmosphere that is electrically charged and is located between 30 and 370 miles (50 and 600 km) from the Earth's surface.

Kuiper Belt

Region of the solar system that is home to millions of frozen objects, such as comets. It stretches from the orbit of Neptune to the inner limit of the Oort cloud.

Light

Electromagnetic radiation with a wavelength visible to the human eye.

Light Pollution

Brightness of the sky originating in street illumination and other artificial lighting, which impedes the observation of dim celestial objects.

Light-Year

Standard astronomical measurement unit equivalent to the distance traveled by light, or any form of electromagnetic radiation, in one year. Equivalent to 6,000,000,000,000 miles (10,000,000,000,000 km).

Lunar Mare

The large, dark regions of the surface of the Moon. They were originally thought to be seas, but they are actually great depressions covered by lava.

Magnetic Field

The area near a magnetic body, electric current, or changing electric field. Planets, stars, and galaxies have magnetic fields that extend into space.

Magnetosphere

Sphere that surrounds a planet with a magnetic field strong enough to protect the planet from the solar wind.

Mantle

Layer that lies between the crust and the core of a planet.

Mass

Measure of the amount of matter in an object.

Matter

The substance of a physical object, it occupies a portion of space.

Meteorite

Rocky or metallic object that strikes the surface of a planet or satellite, where it can form a crater.

Milky Way

The galaxy to which the Sun and the solar system belong. It is visible as a pale band of light that crosses our night sky.

Molecule

Smallest unit of a pure substance that has the composition and chemical properties of the substance. It is formed by one or more atoms.

Moon

The Earth's natural satellite is called the Moon. The natural satellites of other planets are commonly known as moons and have their own proper names.

Nebulae

Clouds of gas and dust in space. Nebulae can be seen when they reflect starlight or when they obstruct light from sources behind them.

Neutron

Electrically neutral subatomic particle. It makes up part of an atom's nucleus (with the exception of ordinary hydrogen).

Neutron Star

Collapsed star consisting mostly of neutrons.

Nova

Star that increases greatly in brightness for several days or weeks and then slowly fades. Most novae probably occur in binary-star systems in which a white dwarf draws in matter from its companion star.

Nuclear Fusion

Nuclear reaction in which relatively light elements (such as hydrogen) form heavier elements (such as helium). Nuclear fusion is the source of energy that makes stars shine.

Oxygen

Chemical element vital to life and to the expansion of the universe. Oxygen makes up 21 percent of the Earth's atmosphere.

Particle

In particle physics, a tiny, individual component of matter with characteristic mass, electrical charge, and other properties.

Perihelion

The point in a celestial body's orbit closest to the Sun. The Earth reaches perihelion on or about January 4, when it is 92,000,000 miles (147,500,000 km) from the Sun.

Photon

Elemental particle responsible for electromagnetic radiation. Photons are the most common particles in the universe.

Planet

Roughly spherical object made of rocks or gas orbiting a star. A planet cannot generate its own light but reflects the light of its parent star.

Polestar

Polaris, a star that lies near the celestial north pole. Polaris is commonly called the North Star. Over thousands of years, other stars will become the polestar.

Proton

Subatomic particle with positive electrical charge. It forms part of the nucleus of an atom.

Radio Galaxy

Active galaxy emitting energy as both radio waves and light. Most of the radio emission originates at the core of the galaxy.

Solar Flare

Immense explosion produced on the surface of the Sun by the collision of two loops of the solar magnetic field.

Solar Mass

Standard unit of mass against which other objects in the universe can be compared. The Sun has 333,000 times as much mass as the Earth.

Space

The medium through which all celestial bodies move.

Space-Time

Four-dimensional conception of the universe in which length, width, and height constitute three dimensions and time acts as the fourth.

Spectral Analysis

Study of spectral lines that provide information about the composition of stars or galaxies and their redshifts.

Spectrum

The result of dispersing the electromagnetic radiation of an object so that the wavelengths of which it is composed can be seen. Dark lines that originate from elements that are present and punctuate the spectrum at specific wavelengths reveal the composition of the object.

Speed of Light

The distance traveled by light in a vacuum in one second (approximately 186,000 miles, or 300,000 km). No object can move faster than the speed of light.

Star

Enormous sphere of gas (generally hydrogen) that radiates light and heat. The Sun is a star.

Star Cluster

Group of stars linked together by gravity. Open clusters are scattered groups of several hundred stars. Globular clusters are dense spheres of several million old stars.

Sunspots

Dark, relatively cool spots on the surface of the Sun. They tend to be located on either side of the solar equator and are created by the solar magnetic field.

Supernova

Explosion of a massive star at the end of its life.

Tide

The effect of the gravitational pull of one astronomical object upon the surface of another. Ocean tides on Earth are an example.

Unstable

Tendency to change from one state into another less energetic one. Radioactive elements decay into more stable elements.

Vacuum

Space occupied by little or no matter.

Van Allen Belt

Radiation zone surrounding the Earth, where the Earth's magnetic field traps solar particles.

Wavelength

Distance between the peaks of any wave of electromagnetic radiation. Radiation with a short wavelength (such as X-rays) has more energy than radiation with a longer wavelength (such as radio waves).

Zenith

Point in the sky 90° above the horizon (that is, immediately above an observer).

Zodiac

Twelve constellations through which the Sun, the Moon, and the planets appear to move.

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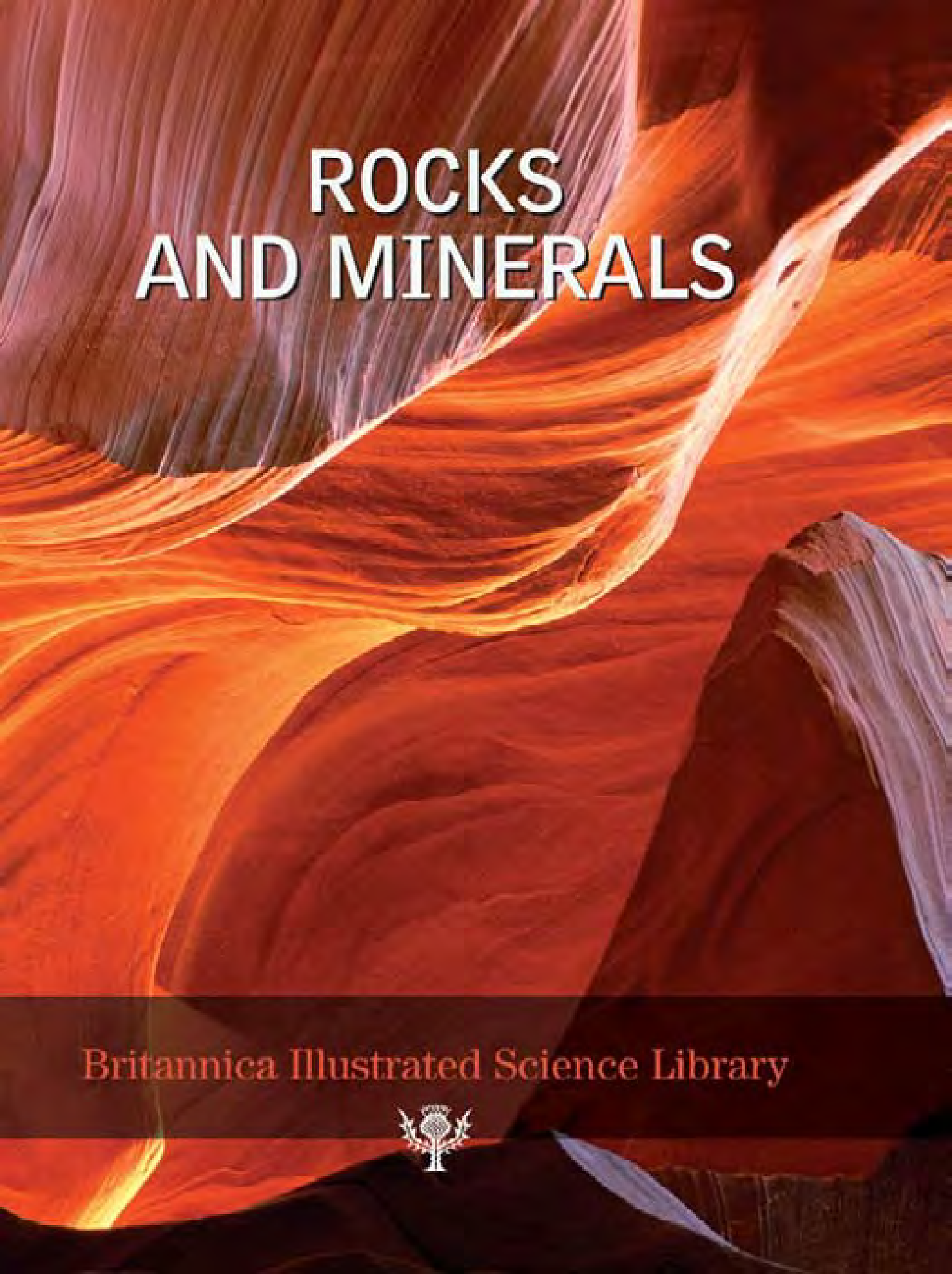
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Rocks and Minerals

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A stone with a blue opal in its center is a product of time, since it forms over millions of years.

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Classes of Rocks

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Use of Rocks and Minerals

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THE MONK'S HOUSE
This orthodox monk lives in a volcanic cave, very close to the 11 Christian churches located in the Ethiopian town of Lalibela.

Memory of the Planet

Rocks, like airplane flight recorders, store in their interior very useful information about what has happened in the past. Whether forming caves in the middle of mountains, mixed among folds, or lying at the bottom of lakes and oceans, stones are everywhere, and they hold clues to the past. By studying rocks, we can reconstruct the history of the Earth. Even the most insignificant rocks can tell stories about other times, because rocks have been around since the beginning of the universe. They were part of the cloud of dust and gases that revolved around the Sun over four billion years ago. Rocks have been silent witnesses to the cataclysms our planet has experienced. They know the cold of the glacial era, the intense heat of the Earth's interior, and the fury of the oceans. They store much information about how external agents, such as wind, rain, ice, and temperature changes, have been altering the planet's surface for millions of years.

For ancient civilizations, stones symbolized eternity. This idea has persisted throughout time because stones endure, but they are recycled time and again. Fifty million years from now, nothing will be as we now know it—not the Andes, nor the Himalayas, nor the ice of Antarctica, nor the Sahara Desert. Weathering and erosion, though slow, will never stop. This should free us from any illusion of the immortality of the Earth's features. What will everything be like in the future? We don't know. The only sure thing is that there will be rocks. Only stones will remain, and their chemical composition, shape, and texture will provide clues about previous geological events and about what the Earth's surface was like in the past. In the pages of this book, illustrated with stunning images, you will find invaluable information about the language of rocks and natural forces in general. You will also learn to identify the most important minerals, know their physical and chemical properties, and discover the environments in which they form.

Did you know that the Earth's crust and its oceans are sources of useful and essential minerals for human beings? Coal, petroleum, and natural gas found in the crust allow us to travel and to heat our homes. Furthermore, practically all the products that surround us have elements provided by rocks and minerals. For example, aluminum is used to produce beverage cans; copper is used in electric cables; and titanium, mixed with other durable metals, is used in the construction of spacecraft. We invite you to enjoy this book. It is full of interesting and worthwhile information. Don't miss out on it!

Dynamics of the Earth's Crust

MOUNTAINS OF SAND
Corkscrew Canyon in Arizona contains an array of shapes, colors, and textures. The sand varies from pink to yellow to red depending on the sunlight it receives.

TRAVERSING TIME 8-11
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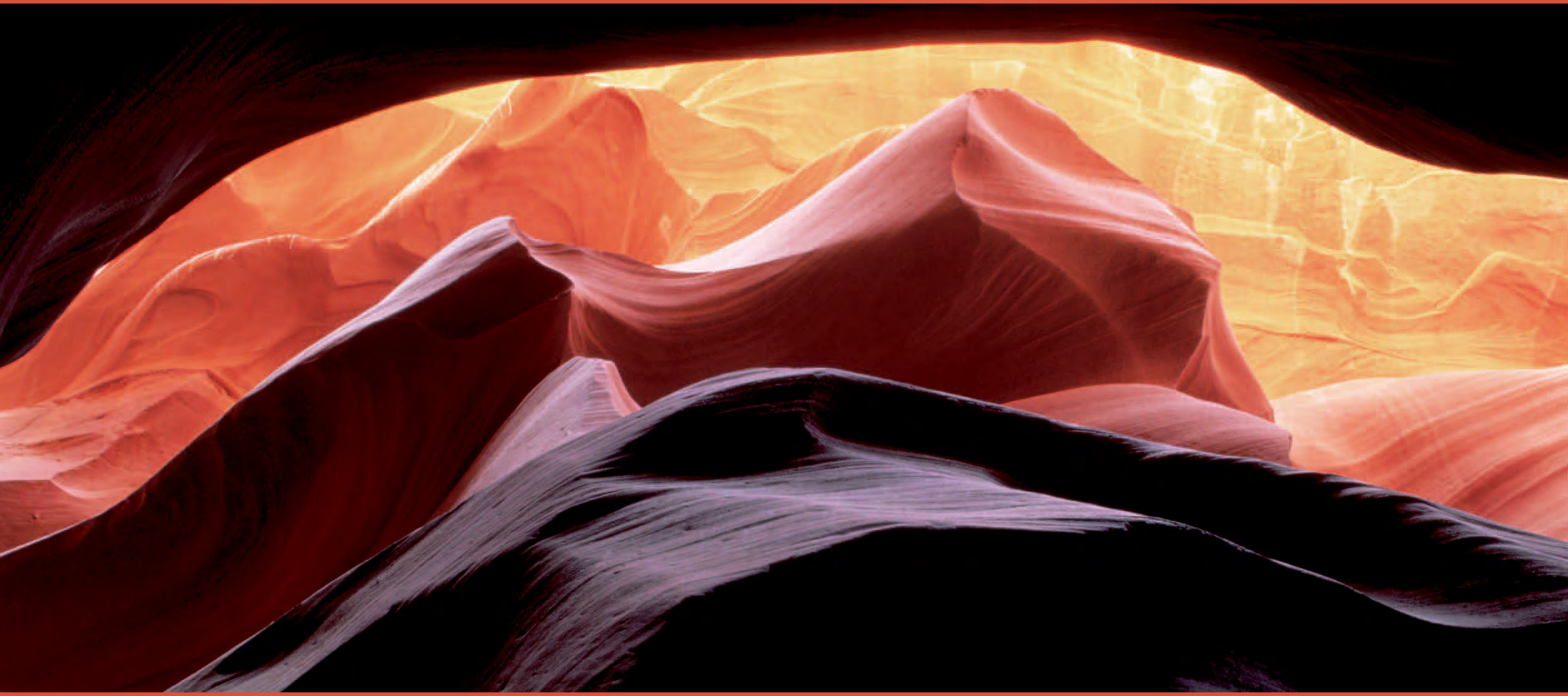


The Earth is like a blender in which rocks are moved around, broken, and crumbled. The fragments are deposited, forming different layers. Then weathering and erosion by wind and rain wear down and transform the rock. This produces mountains, cliffs, and sand dunes, among other features. The deposited material settles into layers of sediment that eventually become sedimentary rock. This rock cycle never stops. In 50 million years, no single mountain we know will exist in the same condition as it does today. ●

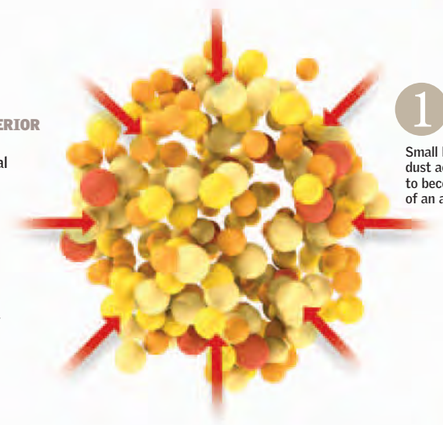
Traversing Time

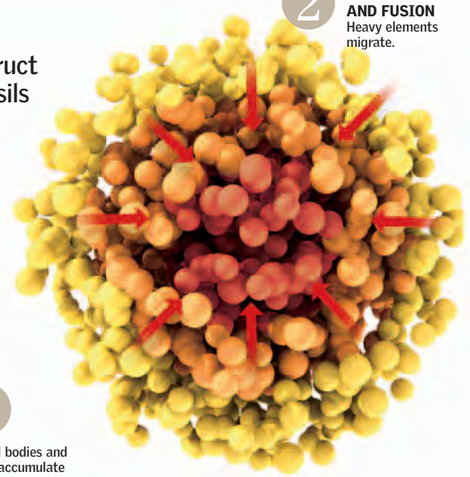
Geologists and paleontologists use many sources to reconstruct the Earth's history. The analysis of rocks, minerals, and fossils found on the Earth's surface provides data about the deepest layers of the planet's crust and reveals both climatic and atmospheric changes that are often associated with catastrophes. Craters caused by the impact of meteorites and other bodies on the surface of the Earth also reveal valuable information about the history of the planet.

Complex Structure

THE FORMATION OF THE INTERIOR

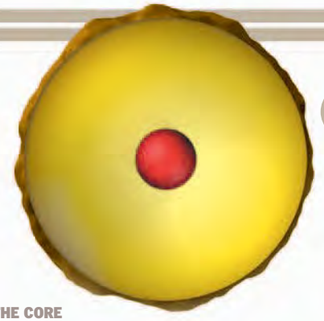
Cosmic materials began to accumulate, forming a growing celestial body, the precursor of the Earth. High temperatures combined with gravity caused the heaviest elements to migrate to the center of the planet and the lighter ones to move toward the surface. Under a rain of meteors, the external layers began to consolidate and form the Earth's crust. In the center, metals such as iron concentrated into a red-hot nucleus.





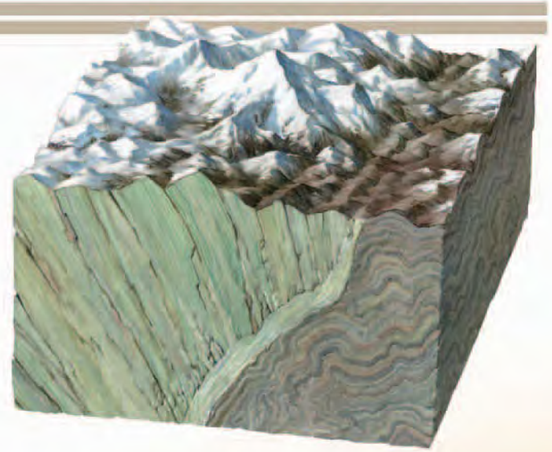
1
Small bodies and dust accumulate to become the size of an asteroid.

2 COLLISION AND FUSION
Heavy elements migrate.



3 METALLIC CORE
The light elements form the mantle.

THE CORE
The Earth's core is extremely hot and is made mostly of iron and nickel.



Mountains

are external folds of the crust produced by extremely powerful forces occurring inside the Earth.

Age in millions of years	4,600	2,500	542	488.3	443.7	416	359.2	299	
ERA	Hadean	Proterozoic	Paleozoic THE ERA OF PRIMITIVE LIFE						
PERIOD	Pregeologic	Precambrian	Cambrian	Ordovician	Silurian	Devonian	Carboniferous	Permian	
EPOCH									

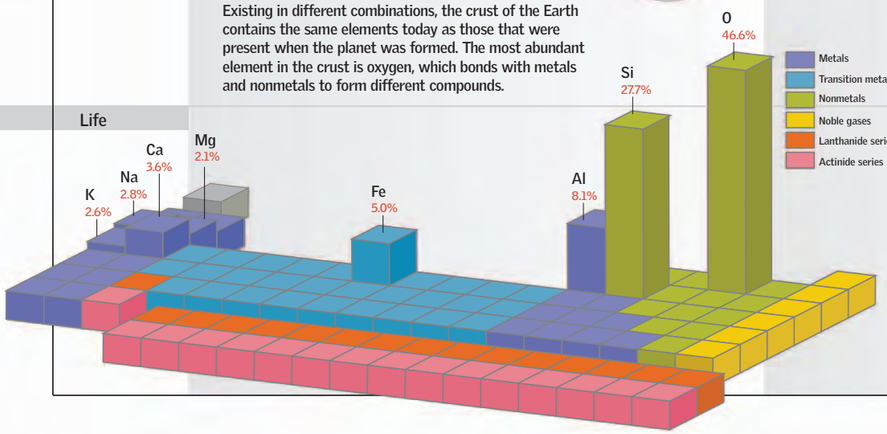
Climate

Consolidation begins under a rain of meteors.

The Earth cools and the first ocean is formed.

ELEMENTS PRESENT ACCORDING TO THE TABLE

Existing in different combinations, the crust of the Earth contains the same elements today as those that were present when the planet was formed. The most abundant element in the crust is oxygen, which bonds with metals and nonmetals to form different compounds.



The oldest minerals, such as zircon, form.

The oldest rocks metamorphose, forming gneiss.

1,100
Rodinia, an early supercontinent, forms.

A meteorite falls in Sudbury, Ontario, Canada.

2,500
Glaciations: White Earth
The Earth undergoes the first of its massive global cooling events (glaciations).

800 Second glaciation
600 Last massive glaciation

542
The supercontinent Panotia forms, containing portions of present-day continents. North America separates from Panotia.

OROGENIES
Geological history recognizes long periods (lasting millions of years) of intense mountain formation called orogenies. Each orogeny is characterized by its own particular materials and location.

The first major orogeny (Caledonian folding) begins. Gondwana moves toward the South Pole.

Laurentia and Baltica converge, creating the Caledonian range. Gneiss forms on the coast of Scotland.

The region that will become North America moves toward the Equator, thus initiating the development of the most important carboniferous formations. Gondwana moves slowly; the ocean floor spreads at a similar speed.

The fragments of continents combine to form a single continent called Pangea.

The Appalachian Mountains form. The formation of slate through sedimentation is at its peak.

Baltica and Siberia clash, forming the Ural Mountains.

Eruptions of basalt occur in Siberia.

Life

THE FIRST ANIMALS
Among the most mysterious fossils of the Precambrian Period are the remains of the Ediacaran fauna, the Earth's first-known animals. They lived at the bottom of the ocean. Many were round and reminiscent of jellyfish, while others were flat and sheetlike.

Temperatures fall. The level of carbon dioxide (CO_2) in the atmosphere is 16 times higher than it is today.

It is thought that the Earth's atmosphere contained far less carbon dioxide during the Ordovician than today. Temperatures fluctuate within a range similar to what we experience today.

By this period, vertebrates with mandibles, such as the placoderms, osteichthyans (bony fish), and acanthodians, have already emerged.

Temperatures were typically warmer than today, and oxygen (O_2) levels attained their maximum.

Hot, humid climates produce exuberant forests in swamplands.

The largest carbon deposits we observe today form where forests previously existed.

THE CAMBRIAN EXPLOSION
Fossils from this time attest to the great diversity of marine animals and the emergence of different types of skeletal structures, such as those found in sponges and trilobites.

TRILOBITES
Marine arthropods with mineralized exoskeletons

SILURIAN
One of the first pisciform vertebrates, an armored fish without mandibles

The rocks of this period contain an abundance of fish fossils.

Areas of solid ground are populated by gigantic ferns.

Amphibians diversify and reptiles originate from one amphibian group to become the first amniotes. Winged insects such as dragonflies emerge.

Palm trees and conifers replace the vegetation from the Carboniferous Period.

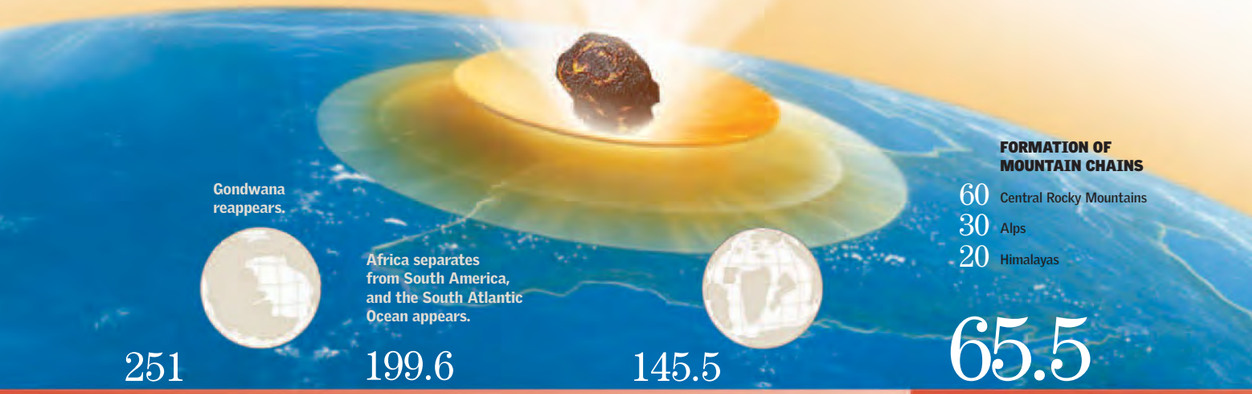
MASS EXTINCTION
Near the end of the Permian Period, an estimated 95 percent of marine organisms and over two thirds of terrestrial ones perish in the greatest known mass extinction.

IMPACT FROM THE OUTSIDE
It is believed that a large meteor fell on Chicxulub, on the Yucatán Peninsula (Mexico), about 65 million years ago. The impact caused an explosion that created a cloud of ash mixed with carbon rocks. When the debris fell back to Earth, some experts believe it caused a great global fire.

62 miles (100 km)

The diameter of the crater produced by the impact of the meteor on the Yucatán Peninsula. It is now buried under almost 2 miles (3 km) of limestone.

The heat caused by the expansion of fragments from the impact together with the greenhouse effect brought about by the spreading of ashes in the stratosphere provoked a series of climatic changes. It is believed that this process resulted in the extinction of the dinosaurs.



Gondwana reappears.

Africa separates from South America, and the South Atlantic Ocean appears.

FORMATION OF MOUNTAIN CHAINS
60 Central Rocky Mountains
30 Alps
20 Himalayas

North America and Europe drift apart. North and South America are joined at the end of this time period. The formation of Patagonia concludes, and an important overthrust raises the Andes mountain range.

The African Rift Zone and the Red Sea open up. The Indian protocontinent collides with Eurasia.

251 | 199.6 | 145.5 | 65.5 | 23.03

Mesozoic THE ERA OF REPTILES
Triassic | Jurassic | Cretaceous

Cenozoic THE AGE OF MAMMALS
Paleogene: Paleocene | Eocene | Oligocene
Neogene: Miocene | Pliocene | Pleistocene | Holocene

Carbon dioxide levels increase. Average temperatures are higher than today.

The level of oxygen (O_2) in the atmosphere is much lower than today.

THE AGE OF FLOWERING PLANTS
At the end of the Cretaceous Period, the first angiosperms—plants with protected seeds, flowers, and fruits—appear.

The global average temperature is at least 62° F (17° C). The ice layer covering Antarctica later thickens.

Temperatures drop to levels similar to those of today. The lower temperatures cause forests to shrink and grasslands to expand.

THE LAST GLACIATION
The most recent period of glaciation begins three million years ago and intensifies at the beginning of the Quaternary period. North Pole glaciers advance, and much of the Northern Hemisphere becomes covered in ice.

Proliferation of insects

Appearance of dinosaurs

The first mammals evolve from a group of reptiles called Therapsida.

Birds emerge.

The dinosaurs undergo adaptive radiation.

ALLOSAURUS
This carnivore measured 39 feet (12 m) long.

ANOTHER MASS EXTINCTION
Toward the end of the Cretaceous Period, about 50 percent of existing species disappear. The dinosaurs, the large marine reptiles (such as the Plesiosaurs), the flying creatures of that period (such as the Pterosaurs), and the ammonites (cephalopod mollusks) disappear from the Earth. At the beginning of the Cenozoic Era, most of the habitats of these extinct species begin to be occupied by mammals.

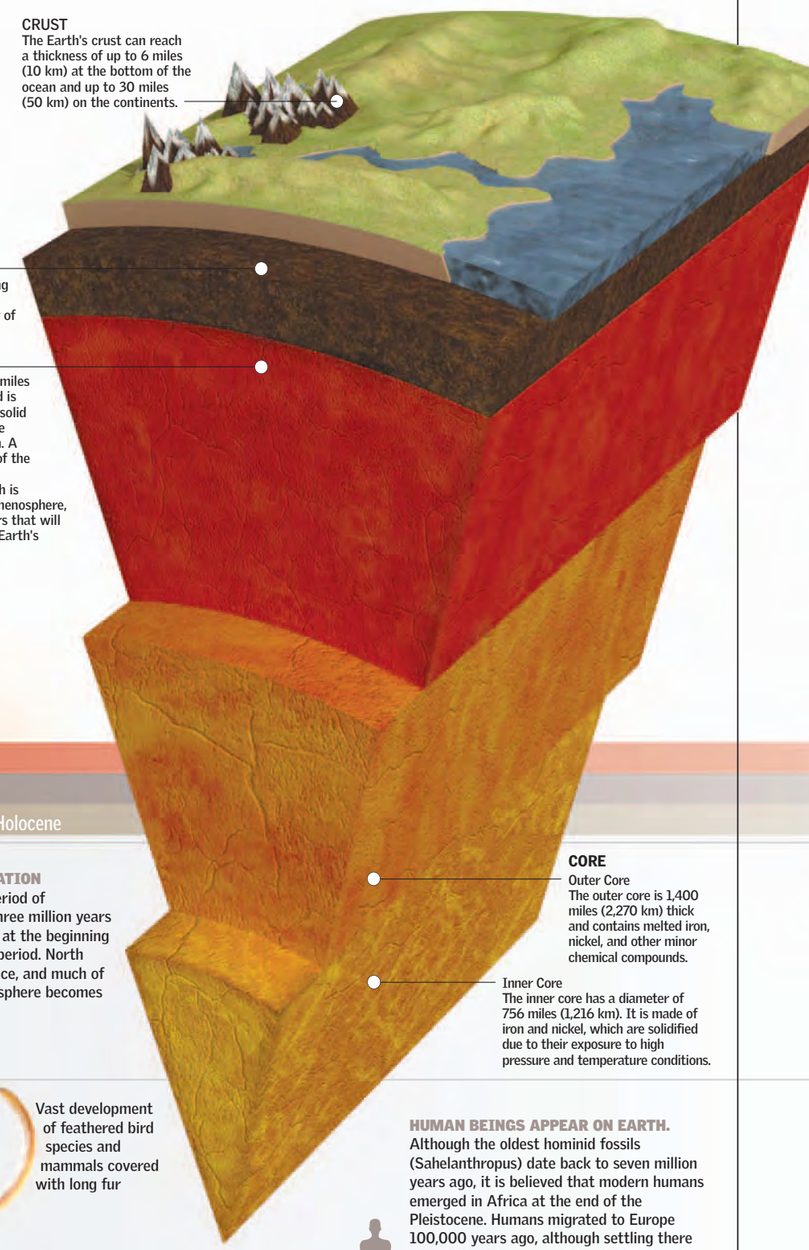
Vast development of feathered bird species and mammals covered with long fur

MAMMOTHS
Mammoths lived in Siberia. The cause of their extinction is still under debate.

HUMAN BEINGS APPEAR ON EARTH.
Although the oldest hominid fossils (Sahelanthropus) date back to seven million years ago, it is believed that modern humans emerged in Africa at the end of the Pleistocene. Humans migrated to Europe 100,000 years ago, although settling there was difficult because of the glacial climate. According to one hypothesis, our ancestors reached the American continent about 10,000 years ago by traveling across the area now known as the Bering Strait.

Elements in Equilibrium

Minerals, such as iron and silicates, are widely spread among the major constituents of the crust. Only the movements of the crust on the molten mantle disrupt their equilibrium.



CRUST
The Earth's crust can reach a thickness of up to 6 miles (10 km) at the bottom of the ocean and up to 30 miles (50 km) on the continents.

LITHOSPHERE
The solid rock coating of the Earth, which includes the exterior of the mantle

MANTLE
The mantle is 1,800 miles (2,900 km) thick and is composed mainly of solid rock. Its temperature increases with depth. A notable component of the upper mantle is the asthenosphere, which is semisolid. In the asthenosphere, superficial rock layers that will eventually form the Earth's crust are melted.

CORE
Outer Core
The outer core is 1,400 miles (2,270 km) thick and contains melted iron, nickel, and other minor chemical compounds.

Inner Core
The inner core has a diameter of 756 miles (1,216 km). It is made of iron and nickel, which are solidified due to their exposure to high pressure and temperature conditions.

Under Construction

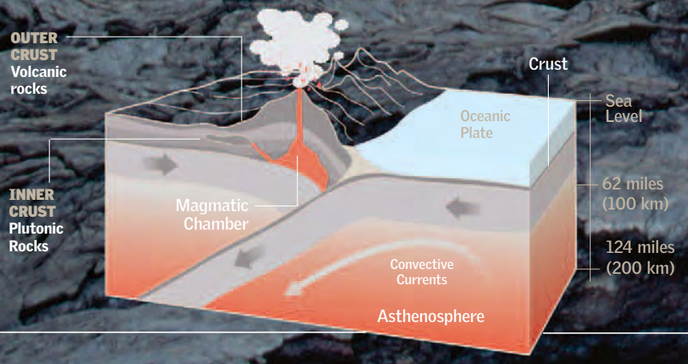
Our planet is not a dead body, complete and unchanging. It is an ever-changing system whose activity we experience all the time: volcanoes erupt, earthquakes occur, and new rocks emerge on the Earth's surface. All these phenomena, which originate in the interior of the planet, are studied in a branch of geology called internal geodynamics. This science analyzes processes, such as continental drift and isostatic movement, which originate with the movement of the crust and result in the raising and sinking of large areas. The movement of the Earth's crust also generates the conditions that form new rocks. This movement affects magmatism (the melting of materials that solidify to become igneous rocks) and metamorphism (the series of transformations occurring in solid materials that give rise to metamorphic rocks).

KILAUEA CRATER
Hawaii

Latitude 19° N
Longitude 155° W

Magmatism

Magma is produced when the temperature in the mantle or crust reaches a level at which minerals with the lowest fusion point begin to melt. Because magma is less dense than the solid material surrounding it, it rises, and in so doing it cools and begins to crystallize. When this process occurs in the interior of the crust, plutonic or intrusive rocks, such as granite, are produced. If this process takes place on the outside, volcanic or effusive rocks, such as basalt, are formed.

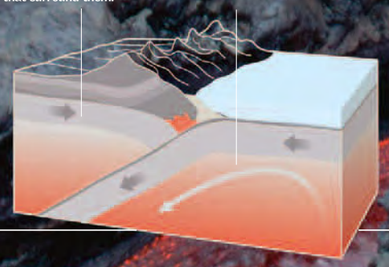


Metamorphism

An increase in pressure and/or temperature causes rocks to become plastic and their minerals to become unstable. These rocks then chemically react with the substances surrounding them, creating different chemical combinations and thus causing new rocks to form. These rocks are called metamorphic rocks. Examples of this type of rock are marble, quartzite, and gneiss.

PRESSURE
This force gives rise to new metamorphic rocks, as older rocks fuse with the minerals that surround them.

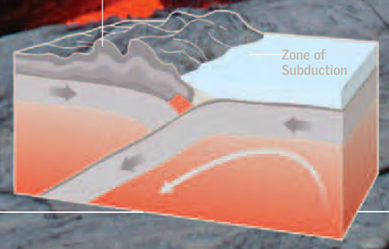
TEMPERATURE
High temperatures make the rocks plastic and their minerals unstable.



Folding

Although solid, the materials forming the Earth's crust are elastic. The powerful forces of the Earth place stress upon the materials and create folds in the rock. When this happens, the ground rises and sinks. When this activity occurs on a large scale, it can create mountain ranges or chains. This activity typically occurs in the subduction zones.

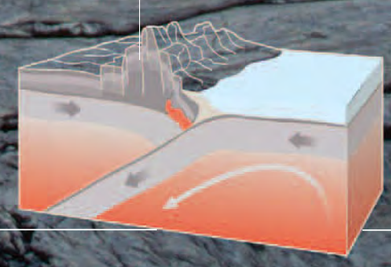
FOLDS
For folds to form, rocks must be relatively plastic and be acted upon by a force.



Fracture

When the forces acting upon rocks become too intense, the rocks lose their plasticity and break, creating two types of fractures: joints and faults. When this process happens too abruptly, earthquakes occur. Joints are fissures and cracks, whereas faults are fractures in which blocks are displaced parallel to a fracture plane.

RUPTURE
When rocks rupture quickly, an earthquake occurs.



A Changing Surface

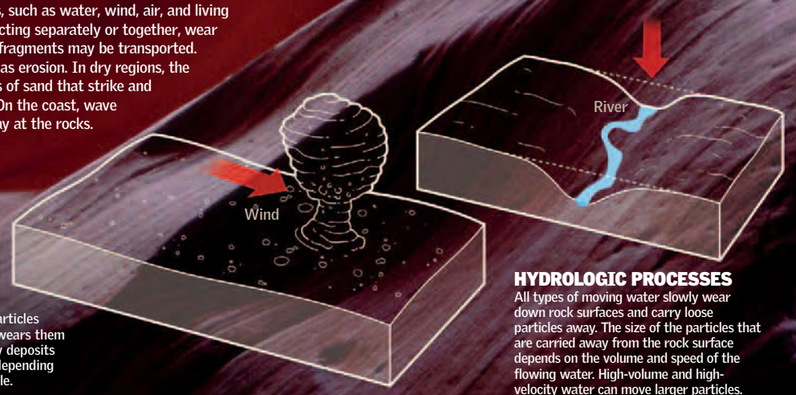
The molding of the Earth's crust is the product of two great destructive forces: weathering and erosion. Through the combination of these processes, rocks merge, disintegrate, and join again. Living organisms, especially plant roots and digging animals, cooperate with these geologic processes. Once the structure of the minerals that make up a rock is disrupted, the minerals disintegrate and fall to the mercy of the rain and wind, which erode them.

CORKSCREW CANYON
Arizona

Latitude 36° 30´ N
Longitude 111° 24´ W

Erosion

External agents, such as water, wind, air, and living beings, either acting separately or together, wear down, and their loose fragments may be transported. This process is known as erosion. In dry regions, the wind transports grains of sand that strike and polish exposed rocks. On the coast, wave action slowly eats away at the rocks.



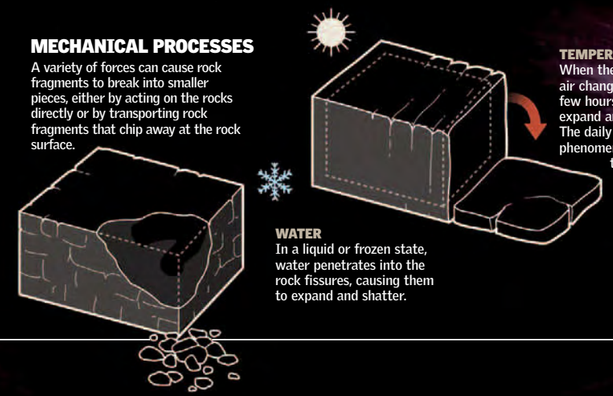
EOLIAN PROCESSES
The wind drags small particles against the rocks. This wears them down and produces new deposits of either loess or sand depending on the size of the particle.

HYDROLOGIC PROCESSES
All types of moving water slowly wear down rock surfaces and carry loose particles away. The size of the particles that are carried away from the rock surface depends on the volume and speed of the flowing water. High-volume and high-velocity water can move larger particles.

Weathering

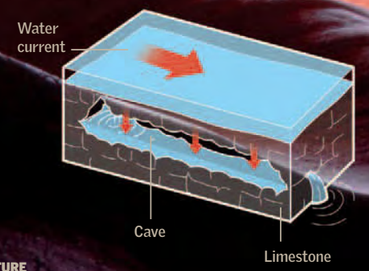
Mechanical agents can disintegrate rocks, and chemical agents can decompose them. Disintegration and decomposition can result from the actions of plant roots, heat, cold, wind, and acid rain. The breaking down of rock is a slow but inexorable process.

MECHANICAL PROCESSES
A variety of forces can cause rock fragments to break into smaller pieces, either by acting on the rocks directly or by transporting rock fragments that chip away at the rock surface.



WATER
In a liquid or frozen state, water penetrates into the rock fissures, causing them to expand and shatter.

CHEMICAL PROCESSES
The mineral components of rocks are altered. They either become new minerals or are released in solution.



TEMPERATURE
When the temperature of the air changes significantly over a few hours, it causes rocks to expand and contract abruptly. The daily repetition of this phenomenon can cause rocks to rupture.

Transportation and Sedimentation

In this process, materials eroded by the wind or water are carried away and deposited at lower elevations, and these new deposits can later turn into other rocks.

Before Rock, Mineral

The planet on which we live can be seen as a large rock or, more precisely, as a large sphere composed of many types of rocks. These rocks are composed of tiny fragments of one or more materials. These materials are minerals, which result from the interaction of different chemical elements, each of which is stable only under specific conditions of pressure and temperature. Both rocks and minerals are studied in the branches of geology called petrology and mineralogy.

From Minerals to Rocks

From a chemical perspective, a mineral is a homogeneous substance. A rock, on the other hand, is composed of different chemical substances, which, in turn, are components of minerals. The mineral components of rocks are also those of mountains. Thus, according to this perspective, it is possible to distinguish between rocks and minerals.

QUARTZ
Composed of silica, quartz gives rock a white color.

MICA
Composed of thin, shiny sheets of silicon, aluminum, potassium, and other minerals, mica can be black or colorless.

GRANITE
Rock composed of feldspar, quartz, and mica

FELDSPAR
A light-colored silicate, feldspar makes up a large part of the crust.

12 million years ago

rock batholiths formed during a period of great volcanic activity and created the Torres del Paine and its high mountains.

TORRES DEL PAINE
Chilean Patagonia

Latitude 52° 20´ S
Longitude 71° 55´ W

Composition	**Granite**
Highest summit	**Paine Grande (10,000 feet [3,050 m])**
Surface	**598 acres (242 ha)**

Torres del Paine National Park is located in Chile between the massif of the Andes and the Patagonian steppes.

CHANGE OF STATE

Temperature and pressure play a prominent part in rock transformation. Inside the Earth, liquid magma is produced. When it reaches the surface, it solidifies. A similar process happens to water when it freezes upon reaching 32° F (0° C).

Minerals

DALLOL VOLCANO
Located in Ethiopia, Dallol is the only non-oceanic volcano on Earth below sea level, making it one of the hottest places on the planet. Sulfur and other minerals that spring from this volcano create very vivid colors.

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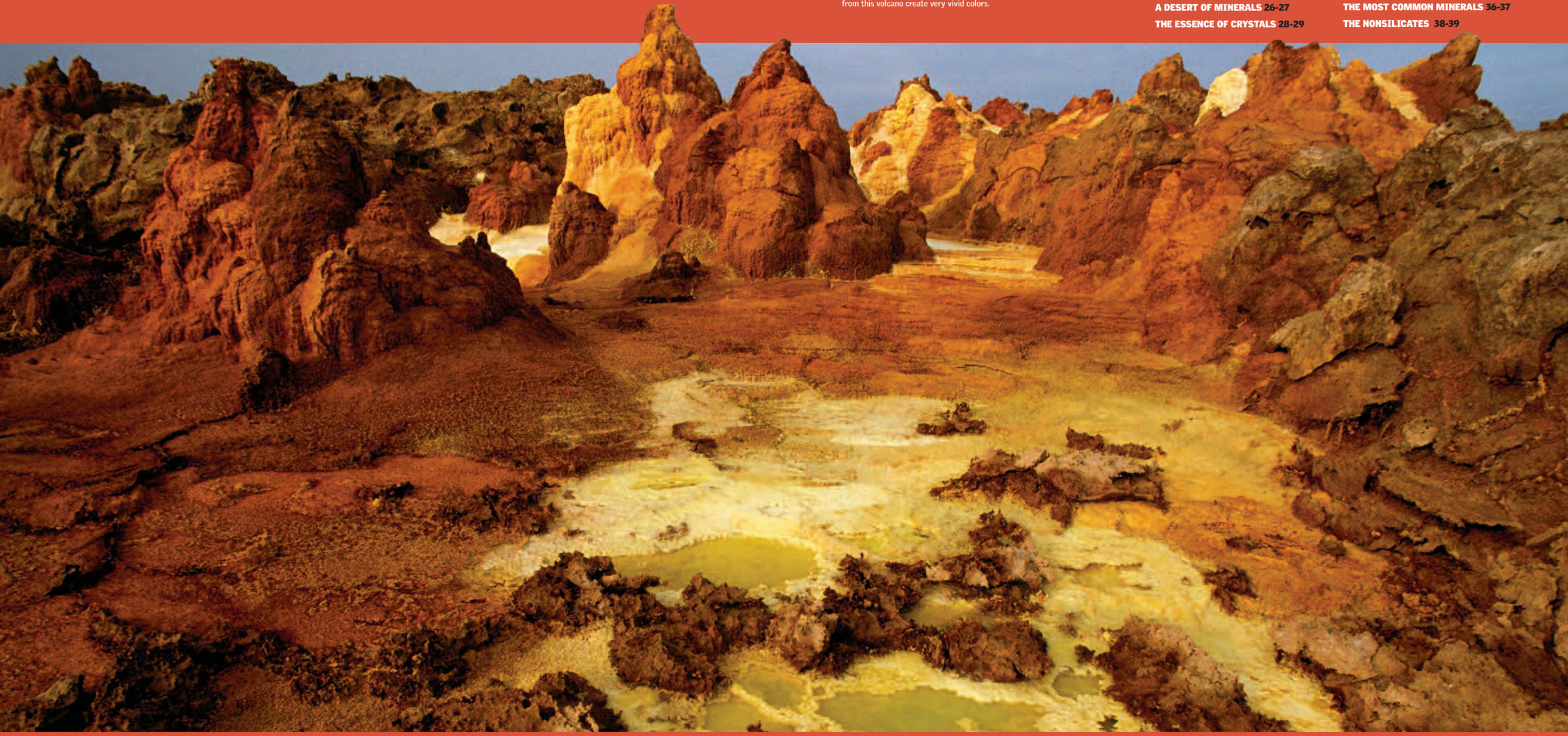


Dallol is basically a desert of minerals whose ivory-colored crust is scattered with green ponds and towers of sulfur salts in shades of orange. Some minerals belong to a very special class. Known as gems, they are sought and hoarded for their great beauty. The most valuable gems are diamonds.

Did you know it took human beings thousands of years to separate metal from rock? Did you also know that certain nonmetallic minerals are valued for their usefulness?

Graphite, for instance, is used to make pencils; gypsum is used in construction; and halite, also known as salt, is used in cooking. ●

You Are What You Have

Minerals are the "bricks" of materials that make up the Earth and all other solid bodies in the universe. They are usually defined both by their chemical composition and by their orderly internal structure. Most are solid crystalline substances. However, some minerals have a disordered internal structure and are simply amorphous solids similar to glass. Studying minerals helps us to understand the origin of the Earth. Minerals are classified according to their composition and internal structure, as well as by the properties of hardness, weight, color, luster, and transparency. Although more than 4,000 minerals have been discovered, only about 30 are common on the Earth's surface.

Components

The basic components of minerals are the chemical elements listed on the periodic table. Minerals are classified as native if they are found in isolation, contain only one element, and occur in their purest state. On the other hand, they are classified as compound if they are composed of two or more elements. Most minerals fall into the compound category.

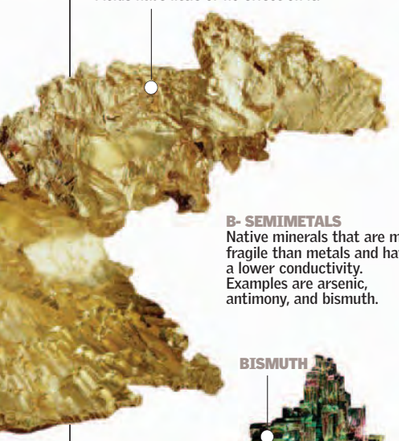
MINERALS COME FROM **112 elements** listed in the periodic table.

1 NATIVE MINERALS

These minerals are classified into:

A- METALS AND INTERMETALS
Native minerals have high thermal and electrical conductivity, a typically metallic luster, low hardness, ductility, and malleability. They are easy to identify and include gold, copper, and lead.

GOLD
An excellent thermal and electrical conductor. Acids have little or no effect on it.

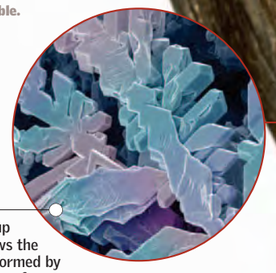


B- SEMIMETALS
Native minerals that are more fragile than metals and have a lower conductivity. Examples are arsenic, antimony, and bismuth.

BISMUTH

C- NONMETALS
An important group of minerals, which includes sulfur

SULFUR



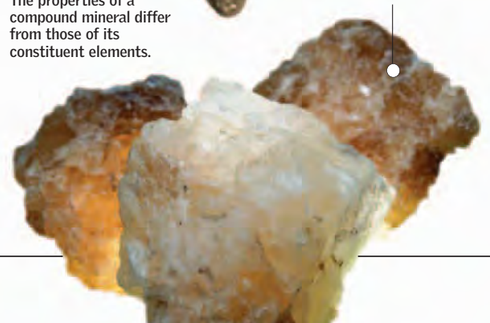
SILVER
The close-up image shows the dendrites formed by the stacking of octahedrons, sometimes in an elongated form.

Microphotograph of silver crystal dendrites

2 COMPOUND MINERALS

Compound minerals are created when chemical bonds form between atoms of more than one element. The properties of a compound mineral differ from those of its constituent elements.

HALITE
is composed of chlorine and sodium.



Polymorphism

A phenomenon in which the same chemical composition can create multiple structures and, consequently, result in the creation of several different minerals. The transition of one polymorphous variant into another, facilitated by temperature or pressure conditions, can be fast or slow and either reversible or irreversible.

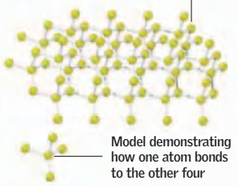
Chemical Composition	Crystallization System	Mineral
$CaCO_3$	Trigonal	**Calcite**
$CaCO_3$	Rhombic	**Aragonite**
FeS_2	Cubic	**Pyrite**
FeS_2	Rhombic	**Marcasite**
C	Cubic	Diamond
C	Hexagonal	Graphite

DIAMOND AND GRAPHITE
A mineral's internal structure influences its hardness. Both graphite and diamond are composed only of carbon; however, they have different degrees of hardness.

Diamond

Graphite

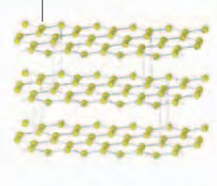
Carbon Atom



Model demonstrating how one atom bonds to the other four

Each atom is joined to four other atoms of the same type. The carbon network extends in three dimensions by means of strong covalent bonds. This provides the mineral with an almost unbreakable hardness.

Hardness of 10
on the Mohs scale



Atoms form hexagons that are strongly interconnected in parallel sheets. This structure allows the sheets to slide over one another.

Hardness of 1
on the Mohs scale

MORE THAN **4,000 types of minerals** have been recognized by the International Association of Mineralogy.

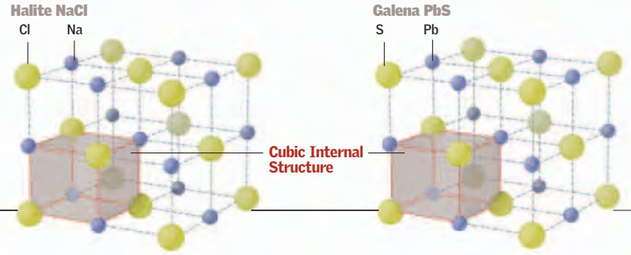
Isotypic Minerals

Isomorphism happens when minerals with the same structure, such as halite and galena, exchange cations. The structure remains the same, but the resulting substance is different, because one ion has been exchanged for another. An example of this process is siderite (rhombic $FeCO_3$), which gradually changes to magnesite ($MgCO_3$) when it trades its iron (Fe) for similarly-sized magnesium (Mg). Because the ions are the same size, the structure remains unchanged.

HALITE AND GALENA

Halite NaCl
Cl Na

Galena PbS
S Pb



Cubic Internal Structure

A Question of Style

Optical properties involve a mineral's response to the presence of light. This characteristic can be analyzed under a petrographic microscope, which differs from ordinary microscopes in that it has two devices that polarize light. This feature makes it possible to determine some of the optical responses of the mineral. However, the most precise way to identify a mineral by its optical properties is to use an X-ray diffractometer.

Color

is one of the most striking properties of minerals. However, in determining the identity of a mineral, color is not always useful. Some minerals never change color; they are called idiochromatic. Others whose colors are variable are called allochromatic. A mineral's color changes can be related, among other things, to the presence of impurities or inclusions (solid bodies) inside of it.

INHERENT COLOR

Some minerals always have the same color; one example is malachite.

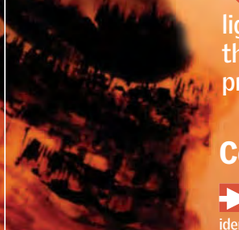
MALACHITE

SULFUR

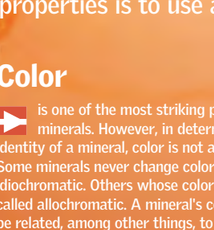
EXOTIC COLOR

A mineral can have several shades, depending on its impurities or inclusions.

QUARTZ



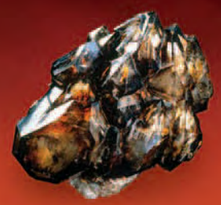
ROCK CRYSTAL
Colorless; the purest state of quartz



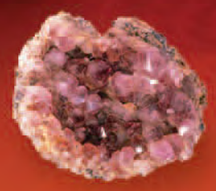
ROSE
The presence of manganese results in a pink color.

Other secondary minerals, known as exotic minerals, are responsible for giving quartz its color; when it lacks exotic minerals, quartz is colorless.

CITRINE
The presence of iron produces a very pale yellow color.



SMOKY
Dark, brown, or gray minerals



AMETHYST
The presence of iron in a ferric state results in a purple color.

COLOR STREAK

More reliable than a mineral's color is its streak (the color of the fine powder left when the mineral is rubbed across a hard white surface).

HEMATITE
Color: Black

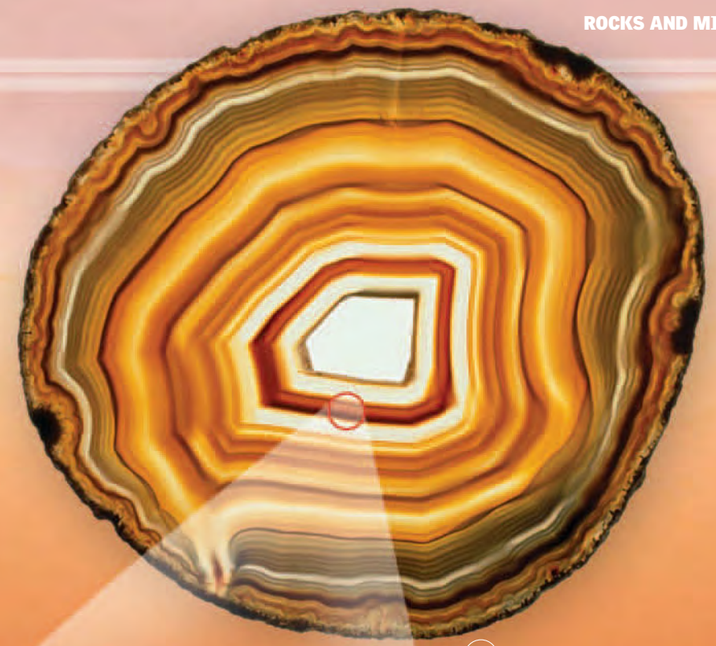
Streak Color: Reddish Brown

Luminescence

Certain minerals emit light when they are exposed to particular sources of energy. A mineral is fluorescent if it lights up when exposed to ultraviolet rays or X-rays. It is phosphorescent if it keeps glowing after the energy source is removed. Some minerals will also respond to cathode rays, ordinary light, heat, or other electric currents.

Refraction and Luster

Refraction is related to the speed with which light moves through a crystal. Depending on how light propagates through them, minerals can be classified as monorefringent or birefringent. Luster results from reflection and refraction of light on the surface of a mineral. In general, it depends on the index of refraction of a mineral's surface, the absorption of incident light, and other factors, such as concrete characteristics of the observed surface (for instance, degree of smoothness and polish). Based on their luster, minerals can be divided into three categories.



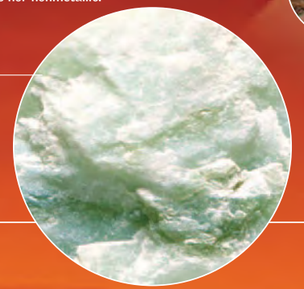
AGATE
A type of chalcedony, a cryptocrystalline variety of quartz, of nonuniform coloring

Agates crystallize in banded patterns because of the environments in which they form. They fill the cavities of rocks by precipitating out of aqueous solutions at low temperatures. Their colors reflect the porosity of the stone, its degree of inclusions, and the crystallization process.

METALLIC
Minerals in this class are completely opaque, a characteristic typical of native elements, such as copper, and sulfides, such as galena.

SUBMETALLIC
Minerals in this class have a luster that is neither metallic nor nonmetallic.

NONMETALLIC
Minerals in this class transmit light when cut into very thin sheets. They can have several types of luster: vitreous (quartz), pearlescent, silky (talc), resinous, or earthy.



Streak

is the color of a mineral's fine powder, which can be used to identify it.

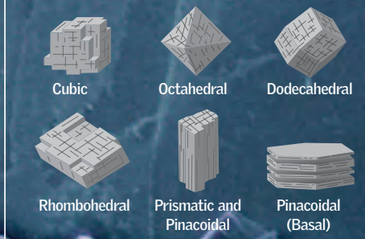
How to Recognize Minerals

A mineral's physical properties are very important for recognizing it at first glance. One physical property is hardness. One mineral is harder than another when the former can scratch the latter. A mineral's degree of hardness is based on a scale, ranging from 1 to 10, that was created by German mineralogist Friedrich Mohs. Another physical property of a mineral is its tenacity, or cohesion—that is, its degree of resistance to rupture, deformation, or crushing. Yet another is magnetism, the ability of a mineral to be attracted by a magnet.

Exfoliation and Fracture

When a mineral tends to break along the planes of weak bonds in its crystalline structure, it separates into flat sheets parallel to its surface. This is called exfoliation. Minerals that do not exfoliate when they break are said to exhibit fracture, which typically occurs in irregular patterns.

TYPES OF EXFOLIATION



TOURMALINE is a mineral of the silicate group.

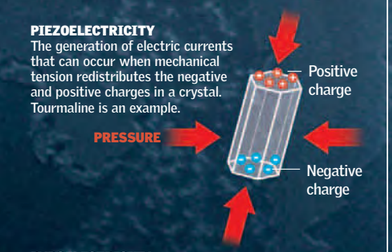
COLOR Some tourmaline crystals can have two or more colors.

FRACTURE can be irregular, conchoidal, smooth, splintery, or earthy.

IRREGULAR FRACTURE An uneven, splintery mineral surface

Electricity Generation

Piezoelectricity and pyroelectricity are phenomena exhibited by certain crystals, such as quartz, which acquire a polarized charge because exposure to temperature change or mechanical tension creates a difference in electrical potential at their ends.



DENSITY reflects the structure and chemical composition of a mineral. Gold and platinum are among the most dense minerals.

7 to 7.5

IS THE HARDNESS OF THE TOURMALINE ON THE MOHS SCALE.

MOHS SCALE ranks 10 minerals, from the softest to the hardest. Each mineral can be scratched by the one that ranks above it.

1. **TALC** is the softest mineral.
2. **GYPSUM** can be scratched by a fingernail.
3. **CALCITE** is as hard as a bronze coin.
4. **FLUORITE** can be scratched by a knife.
5. **APATITE** can be scratched by a piece of glass.
6. **ORTHOCLASE** can be scratched by a drill bit.
7. **QUARTZ** can be scratched by tempered steel.
8. **TOPAZ** can be scratched with a steel file.
9. **CORUNDUM** can be scratched only by diamond.
10. **DIAMOND** is the hardest mineral.

A Desert of Minerals

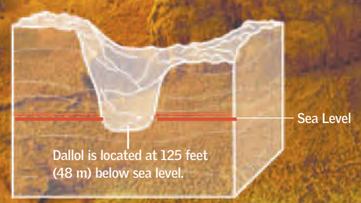
The Dallol region is part of the Afar depression in Ethiopia. It is known as "the devil's kitchen" because it has the highest average temperature in the world, 93° F (34° C). Dallol is basically a desert of minerals with an ivory-colored crust, sprinkled with green ponds and towers of sulfurous salt, in shades of orange, called hornitos (8 to 10 feet [2.5–3 m] high), many of which are active and spit out boiling water.

ETHIOPIA
Latitude 9° N
Longitude 39° E

DALLOL VOLCANO

Location	Afar Depression
Type of volcano	Explosion Crater
Elevation	-125 feet (-48 m)
Last eruption	1926
Annual salt extraction	135,000 tons

CROSS SECTION



3.3 billion tons
(3 billion metric tons)

TOTAL RESERVE OF ROCK SALT IN THE AFAR DEPRESSION

MINERALIZATION PROCESS

Water expelled from its magmatic spring erupts, surfacing as thermal water. When the water evaporates, salt deposits are formed.

3 HEAT
The heat causes the water to evaporate. Salt deposits form on the surface.

2 ASCENT
Water rises to the surface through layers of salt and sulfur deposits.

1 HEAT
Volcanic heat warms the water underground.

YOUNG DEPOSIT
Newer deposits have a white color, which becomes darker over time.

POND
Boiling water emerges from the hornitos and forms small ponds on the surface.

OLD DEPOSIT
The dark coloring indicates that this deposit is several months old.

OLD, INACTIVE HORNITO

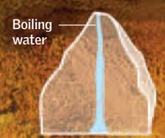
Salt Deposits

Hydrothermal activity occurs when underground water comes in contact with volcanic heat. The heat causes the water to rise at high pressure through layers of salt and sulfur. The water then dissolves the salt and sulfur, which precipitate out as the water cools at the surface. As a result, ponds and hornitos are created. The richness of their coloring may be explained by their sulfurous composition and by the presence of certain bacteria.

TYPES OF HORNITOS

There are two types of hornitos: active ones, which forcefully expel boiling water, and inactive ones, which simply contain salt.

ACTIVE
It expels boiling water, and it is constantly growing.



INACTIVE
Composed of salt, the hornito no longer expels water. It was active in the past.

Hot water rising from the subsoil

8 to 10 feet (2.5-3 m) high

3 EXIT
The hot water is expelled through the hornito.

2 HEAT
Contact with hot rock maintains the water's temperature.

1 ASCENT
The hot water starts to rise underground.

YOUNG, ACTIVE HORNITO

Manual Extraction

Salt is extracted without machinery. Defying the arid climate, inhabitants of the Borena region in southern Ethiopia extract the mineral by hand for a living. They wear turbans to protect themselves from the harmful effects of the Sun. Camels then carry the day's load to the nearest village.

148,800 tons
(135,000 metric tons)
per year

Amount of salt obtained manually in the Afar (or Danakil) depression

Borena

A Black, Muslim, Afar-speaking ethnic group, whose members extract salt in the Dallol. The Borena represent 4 percent of the Ethiopian population.

TURBAN
This piece of clothing protects workers from the extreme temperatures of the desert and the intensity of the Sun while they extract salt.

OTHER MINERALS
In addition to sulfurs and sulfates, potassium chloride, an excellent soil fertilizer, is also extracted from the Dallol.

The Essence of Crystals

All minerals take on a crystalline structure as they form. Most crystals originate when molten rock from inside the Earth cools and hardens. Crystallography is the branch of science that studies the growth, shape, and geometric characteristics of crystals. The arrangement of atoms in a crystal can be determined using X-ray diffraction. The relationship between chemical composition of the crystal, arrangement of atoms, and bond strengths among atoms is studied in crystallographic chemistry. ●

INTERNAL CRYSTALLINE NETWORK

A crystal's structure is repeated on the inside, even in the arrangement of its smallest parts: chlorine and sodium ions. In this case, the electrical forces (attraction among opposite ions and repulsion among similar ones) form cubes, which creates stability. However, different mineral compositions can take many other possible forms.

LEGEND

Chlorine Anion
This nonmetal can only acquire a maximum negative charge of 1.

Sodium Cation
This metal can only acquire a maximum positive charge of 1.

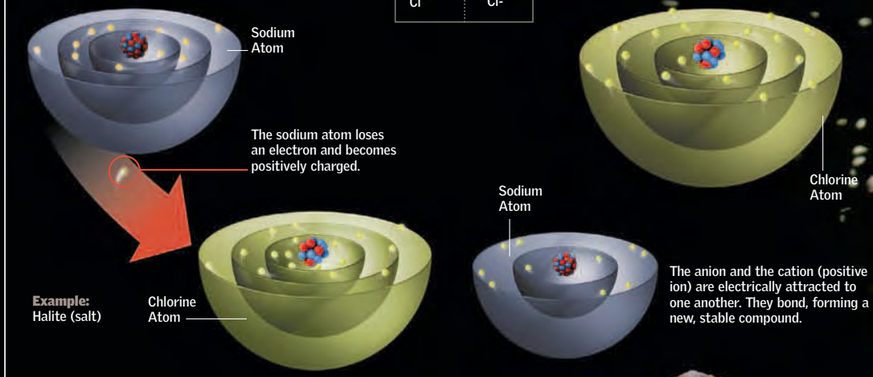
7 Crystalline Systems

The combination of two ions results in a cubic form. When there are more than two ions, other structures are formed.

IONIC BOND

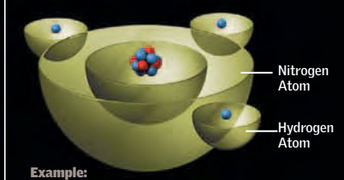
Typical of metallic elements that tend to lose electrons in the presence of other atoms with a negative charge. When a chlorine atom captures an electron from a sodium atom (metallic), both become electrically charged and mutually attract each other. The sodium atom shares an electron (negative charge) and becomes positively charged, whereas the chlorine completes its outer shell, becoming negative.

BEFORE BONDING	AFTER BONDING
Na	Na+
Cl	Cl-



COVALENT BOND

This type of bond occurs between two nonmetallic elements, such as nitrogen and oxygen. The atoms are geometrically organized to share electrons from their outer shells. This way, the whole structure becomes more stable.

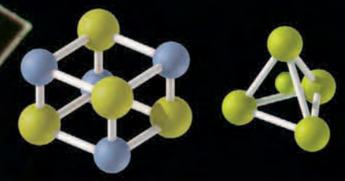


The nitrogen atom needs three electrons to stabilize its outer shell; the hydrogen atom needs only one. The union of all four atoms creates a stable state.así la logran.

CRYSTALS OF COMMON SALT
When salt forms larger crystals, their shape can be seen under a microscope.

BASIC FORMS OF ATOMIC BONDING

This graphic represents an atom's internal crystalline network.



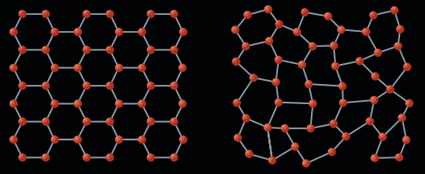
CUBE
Salt (Halite)
1 chlorine atom +
1 sodium atom

TETRAHEDRON
Silica
1 silicon atom +
4 oxygen atoms

CUBIC STRUCTURE
is created through the spatial equilibrium between different ions, which attract each other, and similar ions, which repel each other.

DIFFERENCES BETWEEN CRYSTAL AND GLASS

Glass is an amorphous solid. Because it solidifies quickly, the particles lose mobility before organizing themselves.



ATOMIC MODEL OF A CRYSTAL
The particles combine slowly in regular, stable shapes.

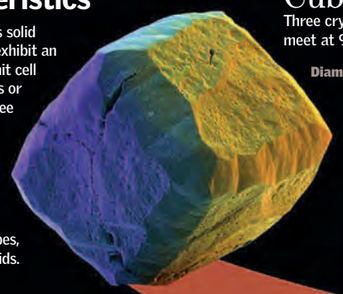
ATOMIC MODEL OF GLASS
Solidification prevents the particles from organizing themselves. This makes the structure irregular.

Crystalline Symmetry

There are more than 4,000 minerals on Earth. They appear in nature in two ways: without an identifiable form or with a definite arrangement of atoms. The external expressions of these arrangements are called crystals, of which there are 32 classes. Crystals are characterized by their organized atomic structure, called a crystalline network, built from a fundamental unit (unit cell). These networks can be categorized into the seven crystalline systems according to the crystal's arrangement. They can also be organized into 14 three-dimensional networks, known as the Bravais lattices.

Typical Characteristics

A crystal is a homogeneous solid whose chemical elements exhibit an organized internal structure. A unit cell refers to the distribution of atoms or molecules whose repetition in three dimensions makes up the crystalline structure. The existence of elements with shared symmetry allows the 32 crystal classes to be categorized into seven groups. These groups are based on pure geometric shapes, such as cubes, prisms, and pyramids.



Cubic
Three crystallographic axes meet at 90° angles.

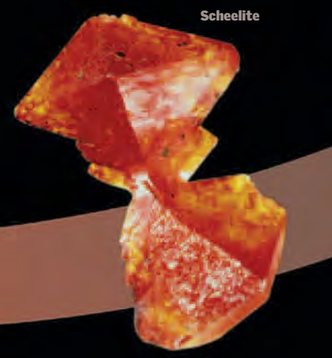
Diamond

Hexagonal
prisms have six sides, with 120° angles. From one end, the cross section is hexagonal.

Vanadinite

Monoclinic
Prisms look like tetragonal crystals cut at an angle. Their axes do not meet at 90° angles.

Brazilianite



Scheelite

Labradorite

Rhodochrosite

Topaz

LEGEND

CRYSTALLINE SYSTEM

BRAVAIS LATTICES

THE MOST COMMON SHAPES

Cube

Octahedron

Rhombo-dodecahedron

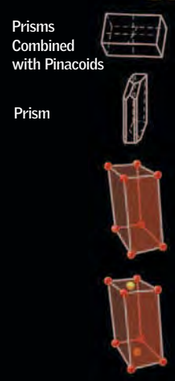
Tetrahedron

Hexagonal Prism

Hexagonal Bipyramid

Hexagonal Prism Combined with Hexagonal Bipyramid

Hexagonal Prism Combined with Basal Pinacoid



Prisms Combined with Pinacoids

Prism

Simple Monoclinic Network

Monoclinic Network Centered on its Bases

Tetragonal Prism and Ditetragonal Prism

Tetragonal Bipyramid

Prism and Bipyramid

Simple Tetragonal

Centered Tetragonal

Triclinic Shapes

Triclinic Network

Trigonal or Rhombohedral Shapes

Trigonal Trapezohedron

Ditrigonal Scalenohedron

Triclinic Network

Pinacoids

Prism and Basal Pinacoid

Bipyramid

Prism and Domes

Prisms, Domes, and Two Pinacoids

Simple Rhombus

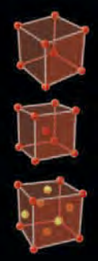
Base-centered Rhombus

Centered Rhombus

Face-centered Rhombus

Bravais Lattices

In 1850, Auguste Bravais demonstrated theoretically that atoms can be organized into only 14 types of three-dimensional networks. These network types are therefore named after him.



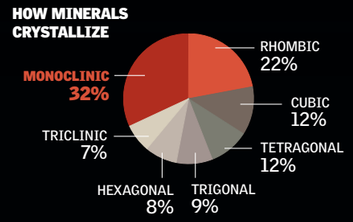
Simple Cubic Network

Body-centered Cubic Network

Face-centered Cubic Network

Only 14 network combinations are possible.

THESE COMBINATIONS ARE CALLED BRAVAIS LATTICES.



There are seven crystalline systems.

The 32 existing crystal classes are grouped into these crystalline systems.

Rhombic
Three nonequivalent crystallographic axes meet at 90º angles.

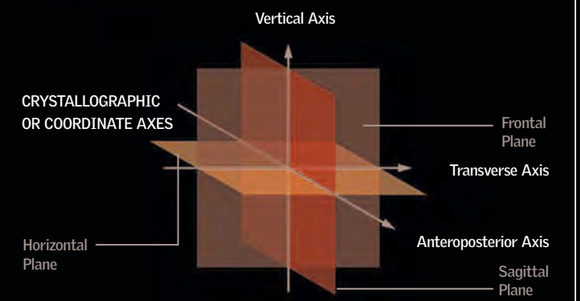
Trigonal
This system includes the most characteristic rhombohedrons, as well as hexagonal prisms and pyramids. Three equal axes meet at 120º, with one axis meeting at 90º to the center.

Triclinic
These crystals have very odd shapes. They are not symmetrical from one end to the other. None of their three axes meet at 90º angles.

Tetragonal
These crystals are shaped like cubes, but one of their facets is longer than the others. All three axes meet at 90º angles, but one axis is longer than the other two.

CRYSTAL SYMMETRY

A crystal's ideal plane of symmetry passes through its center and divides it into two equal, symmetrical parts. Its three crystallographic axes pass through its center. A crystal's longest vertical axis is called "c," its transverse axis "b," and its shortest (from front to back) "a." The angle between c and b is called alpha; the one between a and c, beta; and the one between a and b, gamma.



Precious Crystals

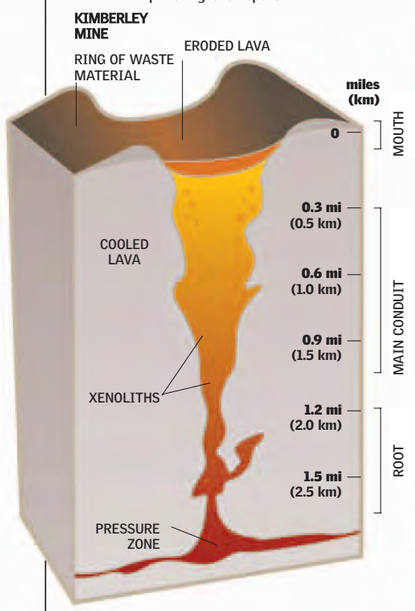
Precious stones are characterized by their beauty, color, transparency, and rarity. Examples are diamonds, emeralds, rubies, and sapphires. Compared to other gems, semiprecious stones are composed of minerals of lesser value. Today diamonds are the most prized gem for their "fire," luster, and extreme hardness. The origin of diamonds goes back millions of years, but people began to cut them only in the 14th century. Most diamond deposits are located in South Africa, Namibia, and Australia. ●

Diamond

Mineral composed of crystallized carbon in a cubic system. The beauty of its glow is due to a very high refraction index and the great dispersion of light in its interior, which creates an array of colors. It is the hardest of all minerals, and it originates underground at great depths.

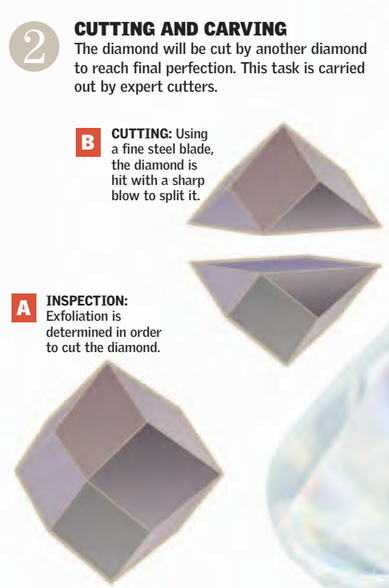
1 EXTRACTION

Diamonds are obtained from kimberlite pipes left over from old volcanic eruptions, which brought the diamonds up from great depths.



2 CUTTING AND CARVING

The diamond will be cut by another diamond to reach final perfection. This task is carried out by expert cutters.



A INSPECTION: Exfoliation is determined in order to cut the diamond.

B CUTTING: Using a fine steel blade, the diamond is hit with a sharp blow to split it.

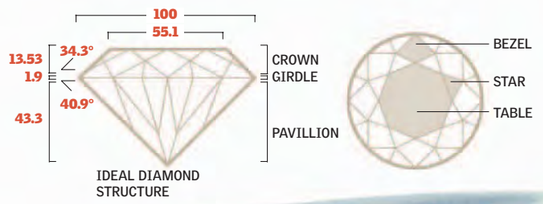
C CARVING: With a chisel, hammer, and circular saws, the diamond is shaped.

27.6 tons (25 metric tons) of mineral must be removed to obtain a **1 carat diamond.**

1 carat = 0.007 ounce (0.2 grams)

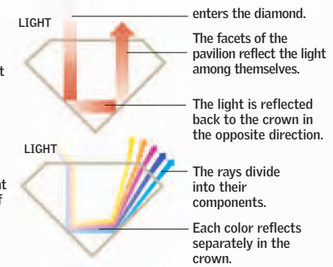
3 POLISHING

The shaping of the facets of the finished gem



BRILLIANCE
The internal faces of the diamond act as mirrors because they are cut at exact angles and proportions.

FIRE
Flashes of color from a well-cut diamond. Each ray of light is refracted into the colors of the rainbow.



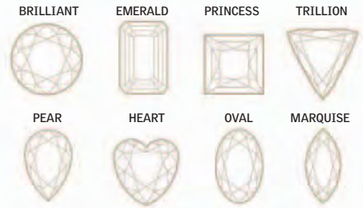
320 microns (0.32 mm)
MEASURED VERTICALLY

THE CHEMISTRY OF DIAMONDS

Strongly bonded carbon atoms crystallize in a cubic structure. Impurities or structural flaws can cause diamonds to show a hint of various colors, such as yellow, pink, green, and bluish white.

COMMON CUTS

A diamond can have many shapes, as long as its facets are carefully calculated to maximize its brilliance.



Gems

Mineral, rock, or petrified material that, after being cut and polished, is used in making jewelry. The cut and number of pieces that can be obtained is determined based on the particular mineral and its crystalline structure.

PRECIOUS STONES

DIAMOND
The presence of any color is due to chemical impurities.

EMERALD
Chromium gives it its characteristic green color.

OPAL
This amorphous silica substance has many colors.

RUBY
Its red color comes from chromium.

SAPHIRE
Blue to colorless corundum. They can also be yellow.

SEMIPRECIOUS STONES

AMETHYST
Quartz whose color is determined by manganese and iron

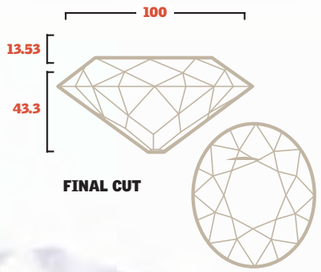
TOPAZ
A gem of variable color, composed of silicon, aluminum, and fluorine

GARNET
A mix of iron, aluminum, magnesium, and vanadium

TURQUOISE
Aluminum phosphate and greenish blue copper

Diamonds in History

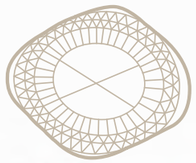
Diamonds are a sign of status, and their monetary value is determined by the law of supply and demand. First discovered by Hindus in 500 BC, diamonds gained fame in the early 20th century when they were advertised in the United States as the traditional gift from husbands to their wives. Some diamonds became famous, however, not only for their economic value but also for the tales and myths surrounding them.

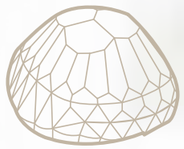


FINAL CUT

The Great Koh-i-noor Diamond

This diamond, which originated in India, now belongs to the British royal family. The raja of Malwa owned it for two centuries, until 1304, when it was stolen by the Mongols. In 1739 the Persians took possession of it. It witnessed bloody battles until finding its way back to India in 1813, after which point it reached the queen.





ORIGINAL CUT
It formerly weighed 186 carats with 30 facets that merged into six facets, which, in turn, became one. This explains its name: Mountain of Light.

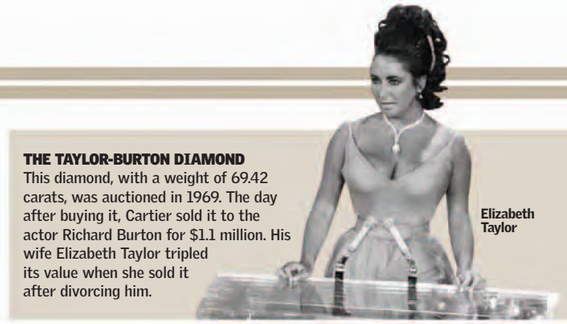
Coronation of the Queen Mother

History

In 1856 this diamond was offered to Queen Victoria as compensation for the Sikh wars. She then had it recut. The Koh-i-noor was diminished to 109 carats.

ONLY FOR WOMEN
Because this diamond was believed to bring unhappiness to men, the superstitious Queen Victoria added a clause to her will stating that the diamond should only be handed down to the wives of future kings.

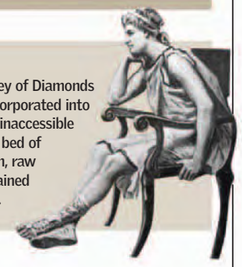
The Queen Mother's Crown



Elizabeth Taylor

THE TAYLOR-BURTON DIAMOND
This diamond, with a weight of 69.42 carats, was auctioned in 1969. The day after buying it, Cartier sold it to the actor Richard Burton for $1.1 million. His wife Elizabeth Taylor tripled its value when she sold it after divorcing him.

THE LEGEND OF THE VALLEY OF DIAMONDS
Alexander the Great introduced the legend of the Valley of Diamonds to Europe. According to this ancient account, later incorporated into the book *The Thousand and One Nights*, there was an inaccessible valley located in the mountains of northern India. The bed of this valley was covered with diamonds. To obtain them, raw meat was thrown in the valley and then fetched by trained birds, which would return it encrusted with diamonds.



The Misfortune of Possessing Hope

The Hope Diamond is legendary for the harm it brought to its owners since being stolen from the temple of the goddess Sita in India. According to the legend, its curse took lives and devoured fortunes. In 1949 diamond expert Harry Winston bought it and in 1958 donated it to the Smithsonian Institution, in Washington, D.C., where it can be viewed by the public.

Legend

Over the years, belief in the curse of the Hope Diamond was reinforced as its owners fell into ruin. Evalyn Walsh McLean, the last private owner of the diamond, did not sell it even after several tragedies befell her family.

1669	Louis XIV acquires the gem. He died in agony of gangrene.
1830	Henry Hope buys the diamond and suffers under the curse; he soon sells it.
1918	While the stone is in the hands of members of the McLean family, the patriarch and two of his daughters die.

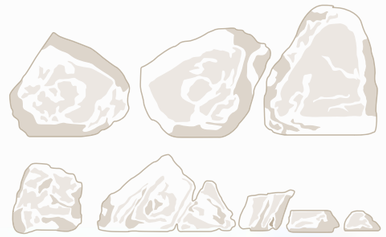
ORIGINAL CUT The purest of blue from the presence of boronic impurities, the diamond's color is also influenced by the presence of nitrogen, which adds a pale yellow shade.

Evalyn Walsh McLean

Cullinan, the Greatest Find

Discovered in 1905 in South Africa, this diamond is the biggest ever found. It was sold to the government of Transvaal two years after its discovery for $300,000 (£150,000). It was then given to Edward VII on the occasion of his 66th birthday. The king entrusted the cutting of the diamond to Joseph Asscher of The Netherlands, who divided it into 105 pieces.

9 LARGE AND 96 SMALL PIECES
Joseph Asscher studied the huge stone for six months to decide how to cut it; he then divided it into nine primary stones and 96 smaller diamonds.



THE GREAT STAR OF AFRICA
This gem is the second largest cut diamond in the world, weighing 530 carats. Because it belongs to the British Crown, it is on display in the Tower of London.

FINAL CUT

530 carats

is the weight of the Cullinan I, the largest stone obtained from the original Cullinan find. It is followed by Cullinan II, which weighs 317 carats and is set in the imperial crown.

The Most Common Minerals

Silicates, which form 95 percent of the Earth's crust, are the most abundant type of mineral. Units of their tetrahedral structure, formed by the bonding of one silicon and four oxygen ions, combine to create several types of configurations, from isolated simple tetrahedrons to simple and double chains to sheets and three-dimensional complex networks. They can be light or dark; the latter have iron and magnesium in their chemical structures.

Structures

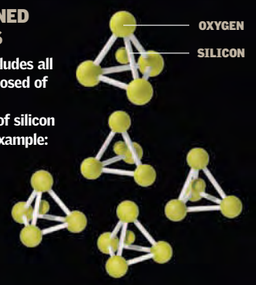
The basic unit of silicates consists of four oxygen ions located at the vertices of a tetrahedron, surrounding a silicon ion. Tetrahedrons can form by sharing oxygen ions, forming simple chains, laminar structures, or complex three-dimensional structures. The structural configuration also determines the type of exfoliation or fracture the silicate will exhibit: mica, which is composed of layers, exfoliates into flat sheets, whereas quartz fractures.

Simple Structure

All silicates have the same basic component: a silicon-oxygen tetrahedron. This structure consists of four oxygen ions that surround a much smaller silicon ion. Because this tetrahedron does not share oxygen ions with other tetrahedrons, it keeps its simple structure.

UNCOMBINED SILICATES

This group includes all silicates composed of independent tetrahedrons of silicon and oxygen. Example: olivine.

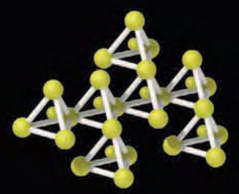


OLIVINE

Complex Structure

This structure occurs when the tetrahedrons share three of their four oxygen ions with neighboring tetrahedrons, spreading out to form a wide sheet. Because the strongest bonds are formed between silicon and oxygen, exfoliation runs in the direction of the other bonds, parallel to the sheets. There are several examples of this type of structure, but the most common ones are micas and clays. The latter can retain water within its sheets, which makes its size vary with hydration.

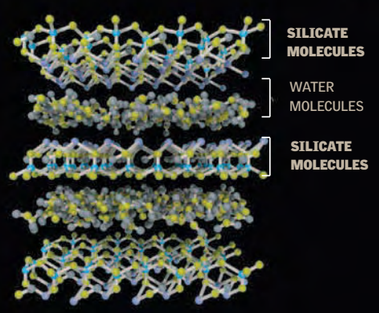
AUGITE



CHAINS

Clays are complex minerals with a very fine grain and a sheetlike structure.

KAOLINITE

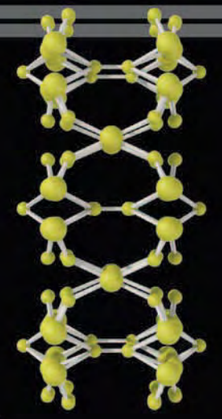


Three-dimensional Structure

Three fourths of the Earth's crust is composed of silicates with complex structures. Silicas, feldspars, feldspathoids, scapolites, and zeolites all have this type of structure. Their main characteristic is that their tetrahedrons share all their oxygen ions, forming a three-dimensional network with the same unitary composition. Quartz is part of the silica group.

THREE-DIMENSIONAL STRUCTURE

Quartz has a complex three-dimensional structure composed only of silicon and oxygen.



LATERAL VIEW

VIEW FROM ABOVE

MINERAL COMBINATIONS

DARK SILICATES

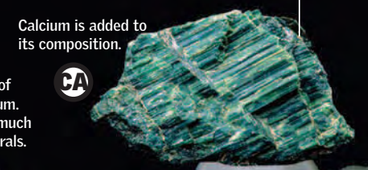
IRON AND MAGNESIUM
EXAMPLE: BIOTITE

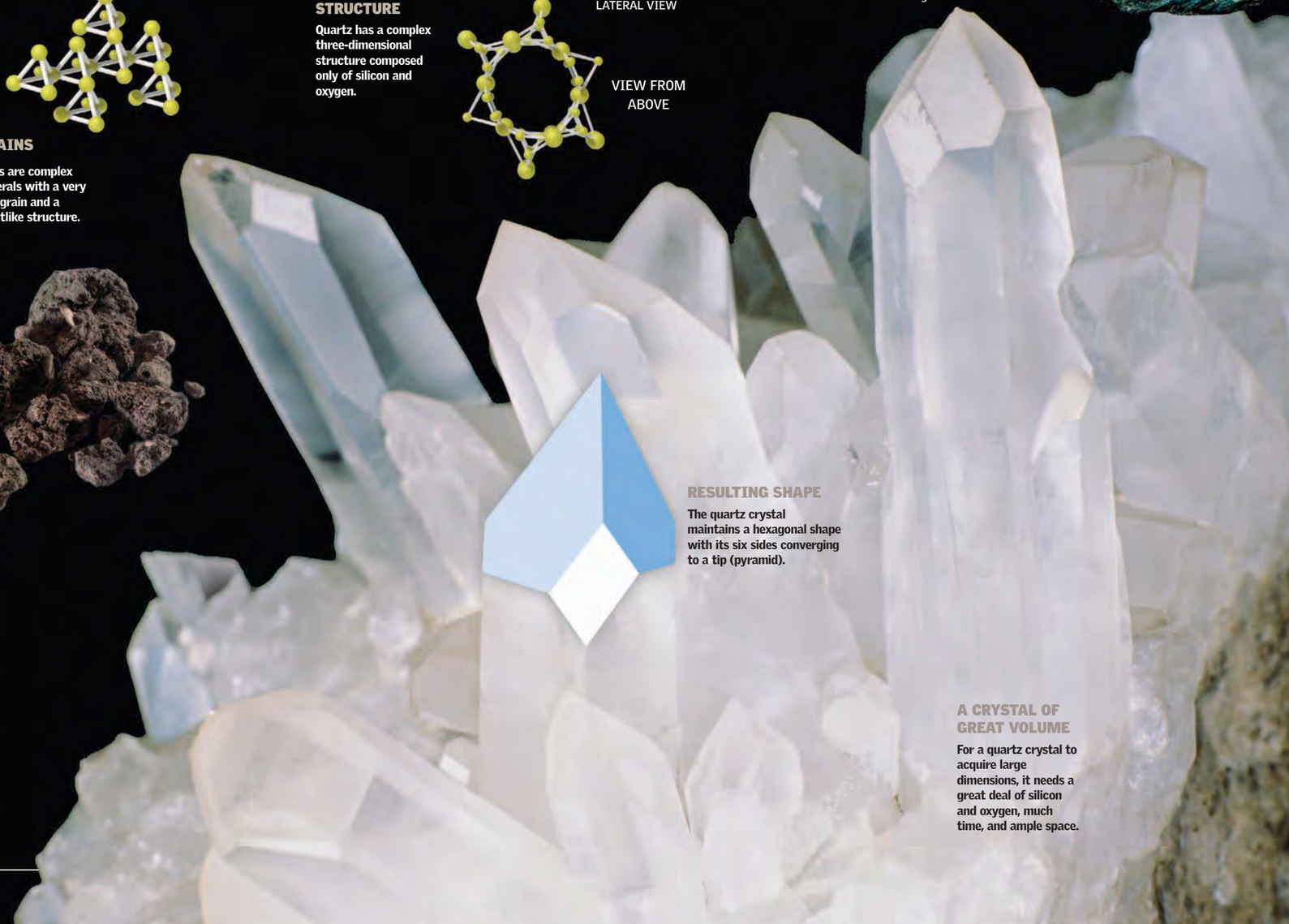
The color and heaviness of this mineral are caused by the presence of iron and magnesium ions. Known as a ferromagnesian mineral, biotite's specific gravity varies between 3.2 and 3.6.

LIGHT SILICATES

MAGNESIUM
EXAMPLE: MINERAL TALC

This mineral contains variable amounts of calcium, aluminum, sodium, and potassium. Its specific gravity is, on average, 2.7—much lower than that of ferromagnesian minerals.





RESULTING SHAPE

The quartz crystal maintains a hexagonal shape with its six sides converging to a tip (pyramid).

A CRYSTAL OF GREAT VOLUME

For a quartz crystal to acquire large dimensions, it needs a great deal of silicon and oxygen, much time, and ample space.

The Nonsilicates

Sulfurs, oxides, sulfates, pure elements, carbonates, hydroxides, and phosphates are less abundant than silicates in the Earth's crust. They make up eight percent of minerals, but they are very important economically. They are also important components of rock. Since ancient times, some have been appreciated for their usefulness or simply for their beauty. Others are still being researched for possible industrial uses.

Very Few in a Pure State

It is rare for native chemical elements to be found in the Earth's crust in a pure state. In general, they must be extracted from other minerals by means of industrial chemical processes. However, they can occasionally be found in rocks in a pure state. Diamonds, for instance, are pure carbon.

Native Elements

In addition to carbon—which forms minerals such as diamond and graphite when crystallized—copper, gold, sulfur, silver, and platinum are other minerals that are found as native elements.

ASSOCIATION
The greenish color indicates the formation of copper sulfate.

FORMATION OF CHALCOPYRITE
Iron, copper, and sulfur are present.

DENDRITES
Microscopic forms that appear when copper solidifies and crystallizes

COPPER

1.2 inches (3 CM)

Copper nuggets can reach a high degree of purity.

MAGNETITE

Oxides

Metal associations with oxygen atoms. Ilmenite, hematite, and chromite are ores from which titanium, iron, and chrome are extracted. Rubies and sapphires are extracted from corundum.

LIMONITE

Hydroxides

Known in chemical terms as a base, these types of minerals appear through the association of oxide with water. Limonite, an iron ore used as pigment because of its reddish color, and bauxite (or aluminum hydroxide) are among the most abundant hydroxides. Bauxite is the ore from which aluminum, a metal that is becoming more and more widely used, is extracted.

APATITE

Phosphates

Both apatite, used as fertilizer, and the semiprecious stone turquoise are phosphates. These materials have a complex structure based on an ion composed of one phosphorus and four oxygen atoms. These ions, in turn, are associated with compound ions of other elements.

GYPSUM ROSETTE

Sulfates

Gypsum, widely used in construction, is a calcium sulfate that forms in the sea and contains water in its structure. Without water, calcium sulfate forms another mineral, anhydrite, which is also used in construction. Barytine is a sulfate from which the metal barium is extracted.

In Alloys and Compounds

As was the case with silicates, it is very difficult to find rocks composed of pure nonsilicate elements—elements with atoms of only one type. The constituent elements of nature, metal and nonmetal, tend to join together and form compounds and alloys. From a chemical perspective, even ice, solidified water, is a compound of hydrogen and oxygen atoms. Some compounds are used as ores, meaning that they are mined for their constituent elements. For example, pure aluminum is obtained from bauxite. Other compound minerals, however, are used for their specific properties, which can be very different from those of each of their constituent elements. This is the case with magnetite, which is an iron oxide.

FLUORITE

Halides

are binary compounds. One halite is table salt (or sodium chloride). Halites have many uses: fluorite is used in the industrial production of steel, and sylvite (potassium chloride) is used as fertilizer.

MALACHITE

Carbonates

Simpler than silicates, minerals in this group are composed of a complex anion associated with a positive ion. Calcium carbonate (calcite, the main component of limestone) and calcium magnesium carbonate (dolomite) are the most common carbonates.

ENCRUSTED IN ROCK
Here crystals are encrusted in slate, a metamorphic rock.

"FOOL'S GOLD"
was an early name for pyrite because of its glitter.

0.04 inch (1 mm)

PYRITE

Sulfides

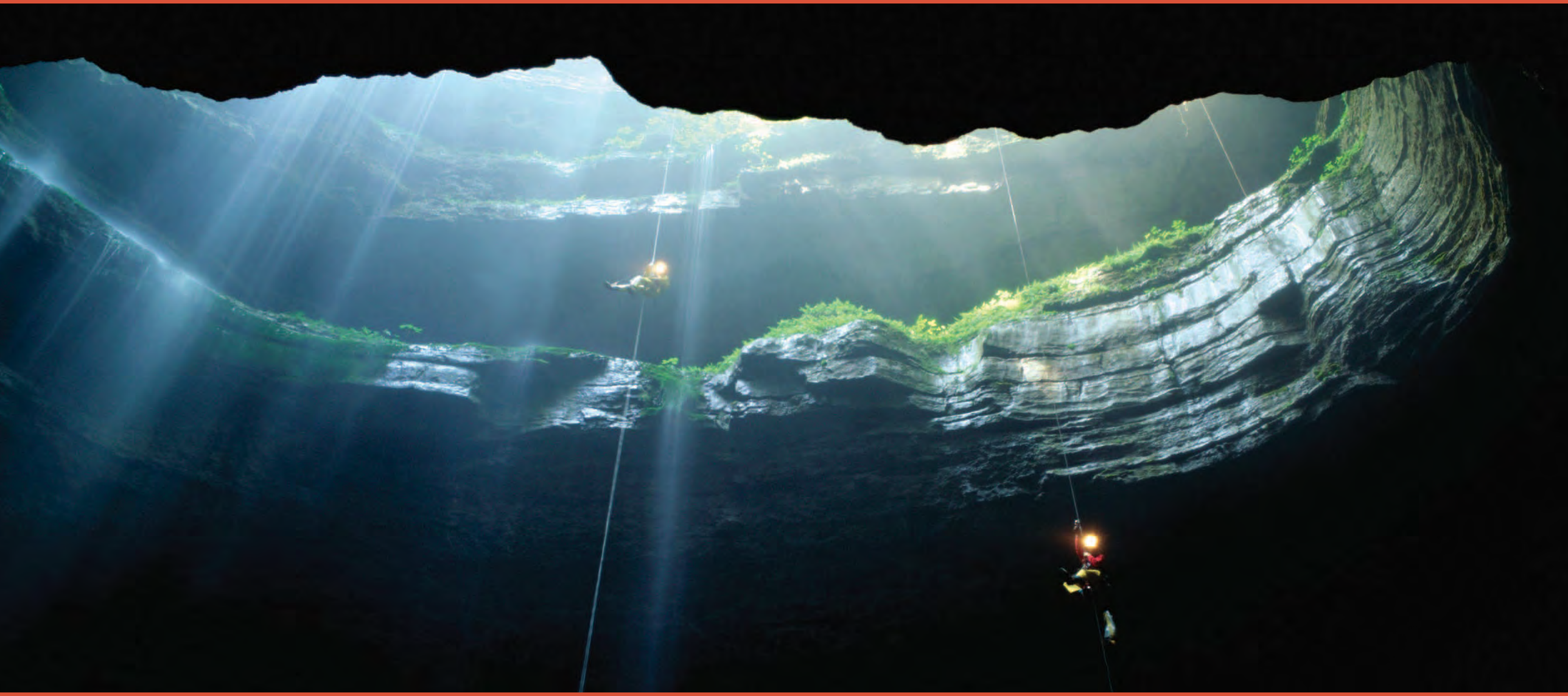
are found in metal ores and are associated with sulfur. Examples of sulfides are pyrite (iron), chalcopyrite (iron and copper), argentite (silver), cinnabar (mercury), galena (lead), and sphalerite (zinc).

STRUCTURE OF PYRITE
The cubic shape of crystals comes from the balanced location of iron and sulfur atoms.

Formation and Transformation of Rocks

SUBTERRANEAN WORLD
This awe-inspiring limestone cave in Neversink Pit (Alabama) looks like no other place on Earth.

ROCKS OF FIRE 42-43
SCULPTED VALLEY 44-45
EVERYTHING CHANGES 46-49
DARK AND DEEP 50-51
IF STONES COULD SPEAK 52-53
METAMORPHIC PROCESSES 54-55
THE BASIS OF LIFE 56-57
DIVINE AND WORSHIPED 58-59



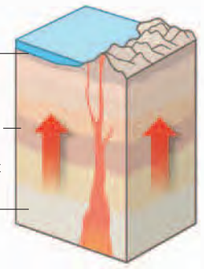
Natural forces create an incredible variety of landscapes, such as deserts, beaches, elevated peaks, ravines, canyons, and underground caves. Settings like the one in the picture amaze us and arouse our interest in finding out what is hidden in the cave's depths. Rocks subjected to high pressure and temperatures can undergo remarkable changes. An initially igneous rock can become sedimentary and later metamorphic. There are experts who overcome every type of obstacle to reach inhospitable places, even in the bowels of the Earth, in search of strange or precious materials, such as gold and silver. They also look for fossils to learn about life-forms and environments of the past. ●

Rocks of Fire

Igneous (from Latin *ignis*, "fire") rocks form when magma coming from the rocky mantle (underneath the crust) rises, cools, and solidifies. When magma comes to the surface as lava and solidifies relatively quickly, it creates extrusive rocks, such as basalt or rhyolite. On the other hand, when magma seeps into caves or between rock layers and slowly solidifies, intrusive igneous rocks, such as gabbro and granite, are formed. These rocks usually have thicker grains and are less dense than the extrusive ones. They are arranged in structures called dikes, sills, and batholiths beneath the surface. Igneous rocks make up most of the Earth's crust.

A Complex Process

The Earth's crust is 44 miles (70 km) deep at most. Farther down, rocks are molten or semimolten, forming magma that rises through the crust and opens paths through cracks, cavities, or volcanoes. Magma can solidify when it is moving or still or when underground or expelled to the surface. All these characteristics together with different mineral compositions create a wide variety of igneous rocks.



CRUST
Rigid, outermost layer

ROCKY MANTLE
1,800 miles (2,900 km) thick

CORE
The outer core is made of solid iron and melted nickel.

BENEATH THE SURFACE
PLUTONIC ROCKS

Most magma is underground in the form of plutons, which undergo a solidification process. This forms intrusive (or plutonic) rocks. When magma intrudes into vertical fissures, the resulting rock formations are called dikes; those between sedimentary layers are sills; and batholiths are masses hundreds of miles long. In general, intrusive rocks crystallize slowly, and their minerals form thick grains. But the solidification process will determine the structure; the rock will be different depending on whether solidification is slow (over millions of years) or fast and whether it loses or gains materials along the way.

GRANITE
Composed of feldspar and quartz crystals, it is rich in sodium, potassium, and silica.

70% SILICA CONTENT

DIKES

The structure of the rock depends on its formation process. Thus, a rock resulting from magma intrusion into a dike will have a structure and coloring different from the rock around it because of having crystallized faster.

SURROUNDING ROCK

INTRUSIVE ROCK

MAIN VENT

LATERAL VENTS

2,200° F (1,200° C)
THE TEMPERATURE OF LAVA IN THE CRUST

SILLS
occupy the spaces between overlying layers of rocks.

MAGMA CHAMBER
receives magma material from the mantle.

MAGMA

LAVA

PYROCLASTS
Rock fragments and ash that spread out over miles

MAGMA RISES
because of the melted rock's low density.

ON THE SURFACE
VOLCANIC ROCK

Volcanic, or extrusive, rocks are those that reach the surface as lava because of volcanic activity. They solidify relatively quickly on the surface. Some, like the obsidians, solidify too quickly to crystallize. This class of rock is distinguished by its viscosity, caused by the low silica content and dissolved gas at the moment of eruption, which give these rocks a particular texture. Highly liquid lava, such as basalt, usually covers large surfaces because it solidifies on the outside while still remaining fluid underground.

BASALT ROCK originates from highly liquid fluid magma that cools quickly.

50% SILICA CONTENT
According to the type of lava

ASH CONE
Composed of pyroclasts of the volcano itself

DIKE
Formed by magma that intruded into a vertical fracture

LACCOLITH
is located between superficial layers.

PLATEAU
Composed of rhyolitic volcanic lava (rich in silicon)

BRANCHING LACCOLITH

VOLCANIC OUTCROPPING

CALDERA
Collapsed volcanic crater covered with water

ERODED LAVA FLOW

SOLID ROCK

LAKE

MUD FLATS

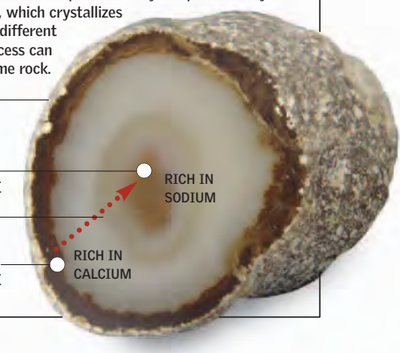
STOCKS
are massive plutons smaller than batholiths.

BATHOLITH
can be an old magma chamber that has solidified over thousands of years.

2,550° F (1,400° C)
MAGMA TEMPERATURE AT A DEPTH OF 125 MILES (200 KM)

Bowen's Reaction Series

Different magma materials solidify at different temperatures. Minerals with calcium, iron, and magnesium crystallize first, giving them a dark coloring (olivine, pyroxene). But sodium, potassium, and aluminum crystallize at lower temperatures, remaining in the residual magma until the end of the process. They are present only in pale-colored rock, which crystallizes later. Sometimes different stages of the process can be seen in the same rock.



AGATE ROCK

LAST LAYER TO CRYSTALLIZE

RICH IN SODIUM

COOLING OF MAGMA

FIRST LAYER TO CRYSTALLIZE

RICH IN CALCIUM

Sculpted Valley

Yosemite National Park is located 200 miles (320 km) east of San Francisco, California. This park is known worldwide for its granite cliffs, waterfalls, crystalline rivers, and forests of giant sequoias. It covers an area of 1,190 square miles (3,081 sq km) and extends along the eastern slopes of the Sierra Nevada range. Yosemite National Park has over three million visitors every year.

Yosemite

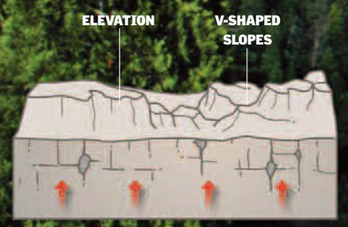
This park has an average elevation of 1,300 to 2,000 feet (400-600 m) above sea level. The geology of the area is mostly composed of a granitic batholith, but five percent of the park is composed of formations from the metamorphism of volcanic and sedimentary rocks. Erosion at different elevations and fracture systems created valleys, canyons, hills, and other current geological formations. The wide separation between fractures and joints is caused by the amount of silica present in the granite and in the metamorphic rocks.

FORMATION OF THE LANDSCAPE

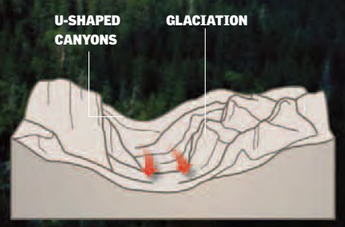
Erosion in the joints resulted in valleys and canyons. The strongest erosive forces of the last several million years have been glaciers, which changed the V-shaped valleys created by rivers into U-shaped glacial valleys.

1 BATHOLITH FORMATION
Almost all rocky formations at Yosemite Park are composed of granite; they belong to the original batholith.

2 ASCENT
Ten million years ago, the Sierra Nevada underwent a tectonic elevation that caused the batholith to emerge.



3 EROSION
One million years ago, the descending flow of glacial ice gave the valley a U shape.



103 Million Years
EL CAPITAN
300-foot-high (1,000 m) granite cliff used for mountain climbing

87 Million Years Ago
HALF DOME
Granite monolith of unique beauty. It is lower than El Capitan, being 2,160 feet (660 m) high.

616 feet (188 m)
FREE FALL

BRIDAL VEIL FALLS
This huge waterfall formed as a consequence of glacial thaw in a "hanging" valley.

103 Million Years Ago
CATHEDRAL ROCKS
One of the main rock formations, with compacted and scratched granite walls

YOSEMITE NATIONAL PARK
United States
Latitude 37° N
Longitude 119° W

Location	**California**
Surface	**1,190 square miles (3,081 sq km)**
Visitors in 2005	**3,380,038**
Opened on	**9/25/1890**
Administered by	**National Park Service**

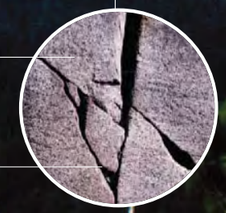
CASCADES

Some rock formations in the park serve as platforms for waterfalls, especially in April, May, and June when the snow melts upstream. The valley has nine waterfalls, five of which are over 1,000 feet (300 m) high; Yosemite Falls is 2,600 feet (800 m) high. This is the highest waterfall in North America and the third highest in the world.

FOREST
The park has three groves of giant sequoias, among other species.

ROCK
Compact granite forming a large batholith

FISSURE
Produced by erosion at rock joints

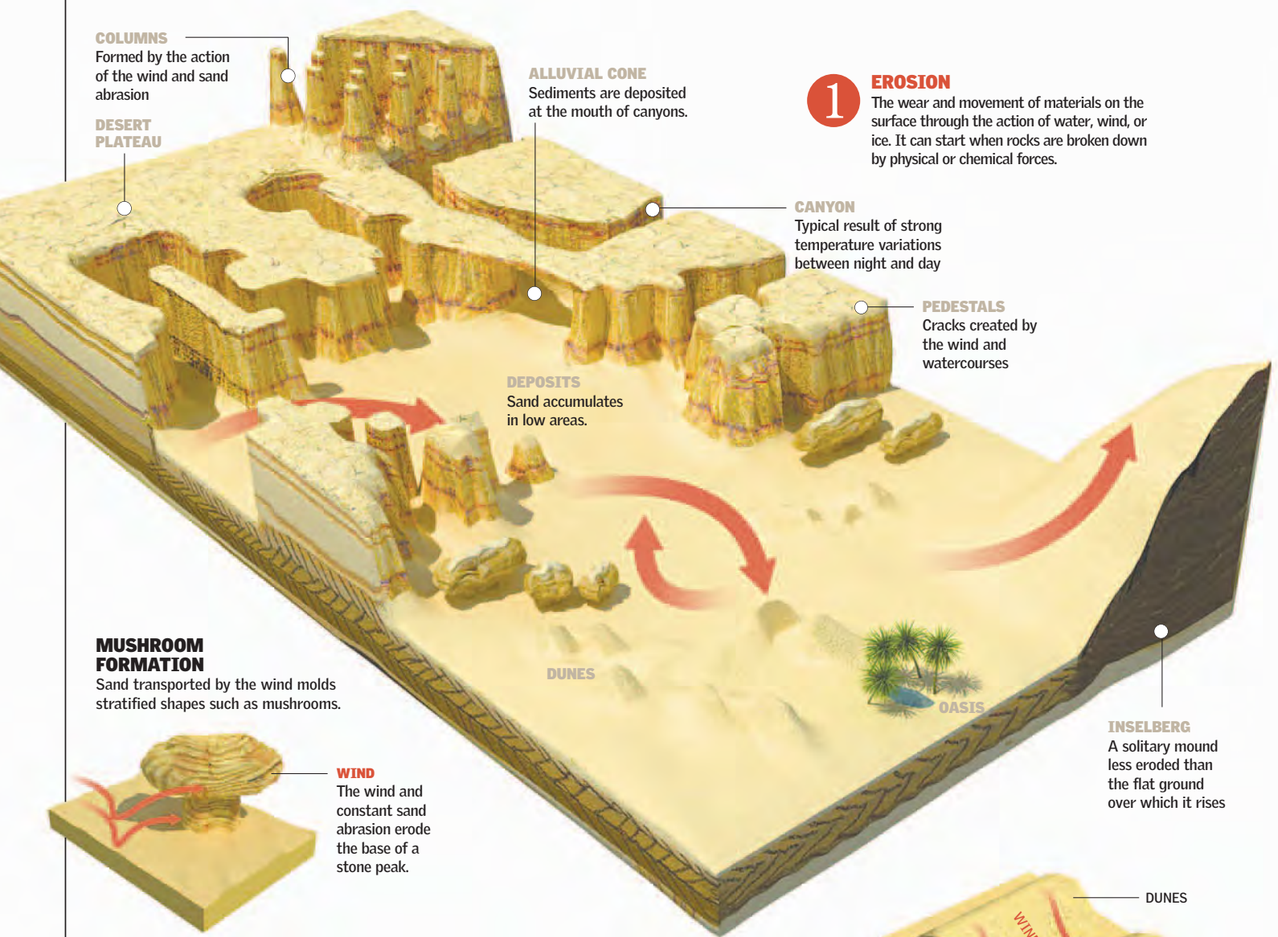


FISSURES

The erosion at rock joints causes fissures within them, and this process leads to the formation of valleys and canyons. The downward flow of the glacial mass of ice cut and sculpted the valley into a U shape. Today this unique landscape attracts great numbers of visitors.

Everything Changes

Wind, ice, and water. These natural elements cause great changes in the Earth's landscape. Erosion and transportation are processes that produce and spread rock materials. Then, when these materials settle and become compacted, new rocks are created, which in turn will revert to sediment. These are sedimentary rocks: the most widely known rocks, they cover 70 percent of the Earth's surface. By observing sedimentary rocks of different ages, scientists can estimate how the climate and the environment have changed.



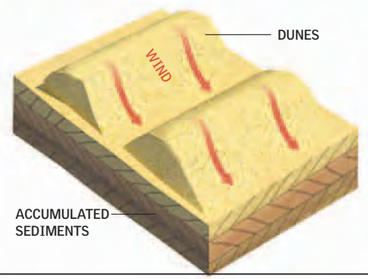
1 EROSION
The wear and movement of materials on the surface through the action of water, wind, or ice. It can start when rocks are broken down by physical or chemical forces.

MUSHROOM FORMATION
Sand transported by the wind molds stratified shapes such as mushrooms.

Deserts

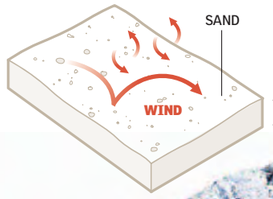
The largest environments sculpted by wind are the deserts. Because of the scarcity of water and the widely varying temperatures, the rock is broken down by physical forces. Rocks fragment and are swept to low-lying areas by occasional water currents. Then sand and mud will be swept away by the wind in a process called deflation. Through this process particles can be transported into semiarid regions.

DUNE EROSION
By transporting sand grains from the crest of the ridge, the wind moves the dunes. The grains can be transported up to 100 feet (30 m) per year.

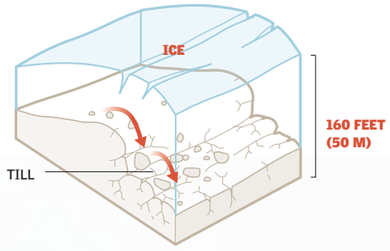


TRANSPORT OF SEDIMENTS

DESERT
TINY GRAINS
In the desert, the wind moves particles in three ways: suspension (very fine grains and dust), transport (the most basic way), and sliding along the surface.



GLACIER
FINE AND HETEROGENEOUS
Glaciers transport rock fragments, which accumulate in moraines. They are made up of a heterogeneous material called till, which, together with rocks, is carried along by the glacier.



GLACIAL CIRQUE
At the upper end of the valley, the walls erode in a semicircular form.

2 TRANSPORT
After erosion, fragments are transported to an area where they will be deposited. In deserts, the wind transports the sand grains, forming dunes; with glaciers, the debris forms frontal and lateral moraines.

SLOPES
Rocks fall from slopes onto glaciers. They are included in the material that makes up the moraine.

CENTRAL MORAINE
forms when two valley glaciers meet, creating only one mass of ice.

CRACKS

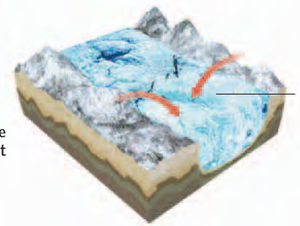
TRANSPORTED ROCK
will be deposited on the moraines.

LATERAL MORAINE
Formed by the fragments accumulated along the sides of the glacier

ERRATICS
are large rock fragments that the glacier transports and deposits.

FINE SEDIMENT
is deposited under the glacier and at its front end. The deposited material is called till.

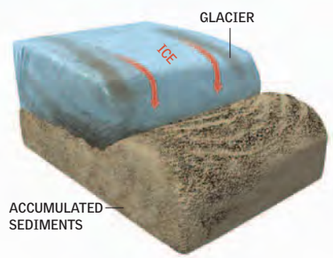
U-SHAPED VALLEYS
Glaciers erode valleys, forming a U shape because erosion is greatest at the bottom.



Glaciers

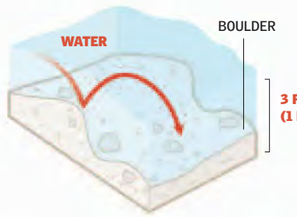
These huge ice masses form on the ground, slowly moving downward through the action of gravity. As they advance, they carry away rocks in their path. At the head of a glacier valley, the walls erode in a semicircle, forming what is called a glacial cirque. The simultaneous, progressive erosion of the walls creates a pyramidal horn, or peak. The valleys through which a glacier has passed are U-shaped instead of the V shape typical of the erosion of river valleys.

TERMINAL MORAINE
Rocks that fall onto the glacier, along with the rock it was already carrying, accumulate at the front of the glacier and form what is called a terminal moraine.

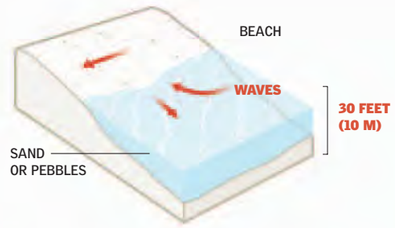


TRANSPORT OF SEDIMENTS

RIVER
GREAT DISTANCES
A river can transport sediments over great distances. Rivers originate in elevated areas, from which they flow to lower areas and then to the sea. When the current gathers speed, it transports big boulders. When the energy is less, the current carries only smaller rocks.

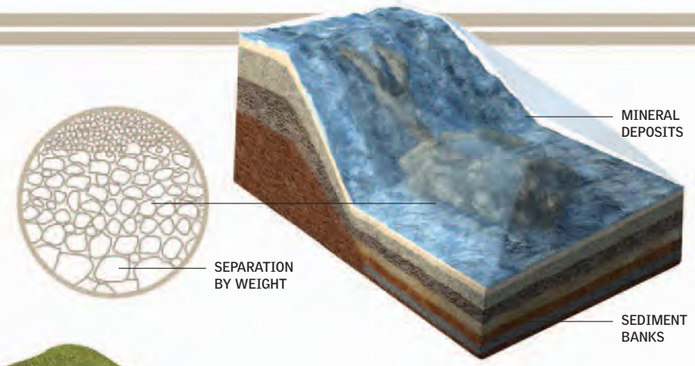


COAST
LOCAL DEPOSITS
After each wave breaks, the undertow descends the beach slope, creating an accumulation of sand that has been transported by the waves in a process called a coastal current. Sand is also transported by rivers, which deposit sediments in their deltas.



CEMENTATION PROCESS

This is the most important process that transforms sediment into rock. Cementation occurs when particles join with the materials precipitated from the water currents. Sedimentary rocks are formed through the union of different minerals that have been dissolved in water. When the water evaporates or cools, the dissolved minerals can precipitate and form deposits that accumulate with other sediments, or they can form rocks on their own. Salts and sandstone are common examples of cemented rocks.



WATERFALLS
Softer rock erodes, forming a cave with a rocky ceiling that will finally crumble and fall.

SLOPE
River valleys are steep because they are composed of layers of hard rock.

CLIFF
A product of lateral undermining

3 SEDIMENTATION
When the currents that transport sediment lose energy, the sediment is deposited in layers and distributed over extensive areas.

RAPIDS
In these geographic features, a high volume of matter is transported by river erosion.

MEANDERS
The outside of the curve is where the most sediment is deposited.

RIVER'S MOUTH
Interrupts the shoreline and delivers continental sediments.

4 COMPACTION
The successive layers of sedimentary deposits compact the lower ones by exerting pressure on them. This gives rise to diagenesis and lithification, processes that will form new rock.

COASTAL PLAIN
A plain that usually lies inward from beach

MARINE ABRASION PLATFORM
Flat surface created by a receding cliff

CAVE
Caves are cut into the rock through abrasion.

ESTUARY
Former river valley that is now flooded. It offers the necessary conditions for depositing much sediment.

SOLID ROCK

CLIFFS
originate through the erosive action of the waves against the base of coastal terrain.

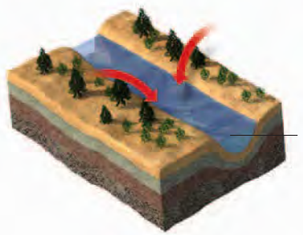
SEDIMENTARY DEPOSIT
Accumulation of sediments transported by coastal (longshore) drift

LAYERS
Different layers of lithified sediments

FORMATION OF V-SHAPED VALLEYS
Unlike glacial valleys, which are eroded in the shape of a U, river valleys are V-shaped.

ALLUVIAL PLAIN
Composed of sediments

SEDIMENTARY DEPOSITS



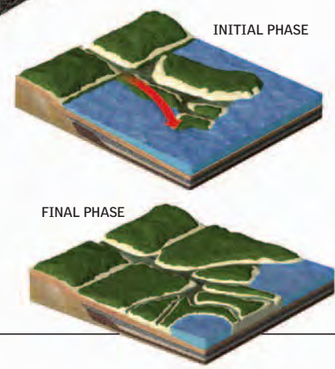
RIVER
Close to the river's source, the current is very strong, and it erodes and digs into the riverbed to form V-shaped valleys.

UNDERWATER SLOPE
Along the coast, the effects of erosion caused by waves are easy to spot. Cliffs are created through the erosive action of the waves against the base of coastal terrain. As the erosion progresses, the undermining of the cliff's base leaves higher rock layers jutting outward, which then collapse. The cliff recedes, leaving a flat surface in the form of a bank called an abrasion platform.

Rivers

Close to their source, rivers flow through areas of high elevation. The water descends there with great force and energy, which enables the current to transport large boulders. At low elevations, rivers flow more smoothly over sediments, forming meanders and eroding laterally. On reaching the coast, rivers deposit sediments and form estuaries or deltas.

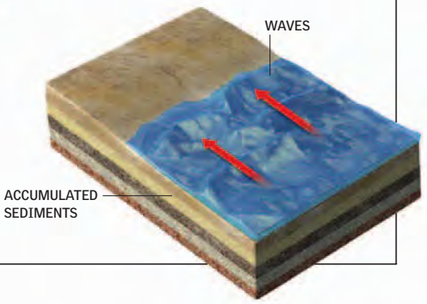
DELTA FORMATION
The sediment deposited at the river's mouth creates a delta, an area with sandbars through which the river flows in various directions.



Coasts

Ocean coasts are the most changing landscapes in the Earth's geography thanks to a process called coastal drift. The elements that build up the coastline—wind, rain, and waves—also erode and mold it. Thus, the waves that bring the sediments that form beaches and carry them away are the same waves that can create or knock down a cliff or cave. Its remnants will be the building material for another beach, along with the sediment that comes from rivers and their deltas.

BEACH FORMATION
Beaches are formed from the gradual deposits of waves in low-energy coastal zones. They can be made of fine sediment, such as mud and sand, or of larger materials, such as boulders.

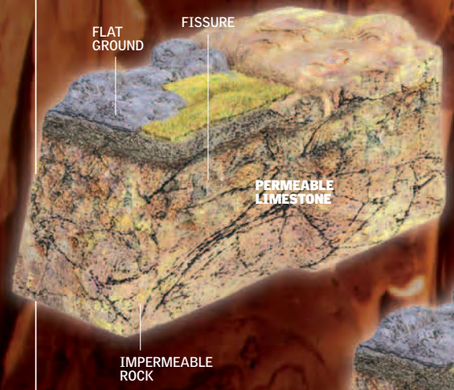


Dark and Deep

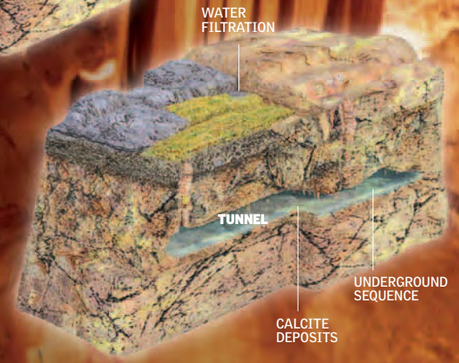
A cave is a hollow space created essentially through the chemical action of water on a soluble, usually chalky, material. Caves have three structures: stalactites (conical structures that hang from the cave ceiling), stalagmites (structures that jut from the cave floor), and columns (created when stalactites and stalagmites join). The cycle of cave formation is called the karst cycle, which lasts a total of around one million years. For this reason, young, active caves have noisy streams and cascades, whereas old caves are silent wonders decorated with stalagmites, stalactites, and columns.

The Karst Cycle

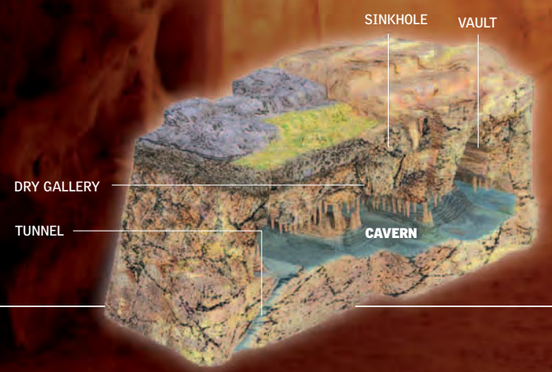
When water dissolves high calcium content rock through the corrosive effect of carbonic acid, it forms networks of conduits and galleries. The initial fissures widen not only through this chemical process but also mechanically through the abrasive action of pebbles and other insoluble elements. Water is filtered until it reaches lower levels, leaving in its wake openings arranged in levels and separated by vertical pits and passages that connect the different levels.



1 STRUCTURE OF THE STRATUM OF A CAVE
The ground's original structure is composed of permeable limestone. It has fissures through which river or rainwater is filtered. This starts the erosive process.



2 INITIAL CAVE
Water, following the contour of the terrain, forms an underground river. The first calcite or calcium carbonate deposits start to form in the shape of stalactites.



3 EXTENDED CAVE SYSTEM
Formed when several tunnels are joined together. Sometimes the surface of the soil starts to sink, creating sinkholes. If the cave extends below the water table, tunnels are formed.

COLUMN
If stalactites and stalagmites grow until they join together, they become columns.

130 feet
(39 m)
THE HIGHEST COLUMN IN THE WORLD

STALAGMITE
Water droplets containing dissolved carbonate create stalagmites as they drip down.

100 feet
(30 m)
THE TALLEST STALAGMITE IN THE WORLD

Stalactite Formation

Limestone is a rock composed almost exclusively of calcium carbonate, which dissolves in naturally acid water. Rainwater absorbs carbon dioxide from the air and microorganisms from the ground, becoming a weak acid. When filtered, it can dissolve limestone over time. If this water drips into a cave, it loses carbon dioxide to the air and deposits the excess calcium in stalactites and stalagmites, thereby maintaining chemical equilibrium. Stalactites are excellent examples of chemical sedimentary rocks.

65° F
(18° C)
IDEAL TEMPERATURE FOR THE PRECIPITATION OF CARBONATE

1 WATER DROPLET
Every stalactite starts from a simple water droplet containing dissolved salts.

2 CALCITE
When the droplet falls, it leaves behind a narrow calcite trail.

3 MORE LAYERS
Each successive droplet that falls deposits another fine calcite layer.

4 INTERIOR TUBE
The layers form around a narrow pipe (0.02 inch [0.5 mm]) through which the water seeps.

5 STALACTITE
If many droplets are deposited over this pipe, stalactites are formed.

STALACTITES
can form on ceilings and cement floors, although they form much faster in a cave's natural environment that contains carbon-rich solutions.

23 feet
(7 m)
THE BIGGEST STALACTITE IN THE WORLD

Other Formations

A passing underground current forms two types of landscape: canyons and tunnels. Underground rivers and waterfalls above the water table create deep, undulating canyons by eroding and dissolving limestone and by abrading the rock layers with sediment. Below the water table, caves are full of water that moves slowly, dissolving walls, floors, and ceilings of carbonate rock to create tunnels.

CANGO CAVES
SOUTH AFRICA
Latitude 33º S
Longitude 18º E

Length	3.3 miles (5.3 km)
Depth	200 feet (60 m)
Location	East of Cape Town

CANGO CAVES

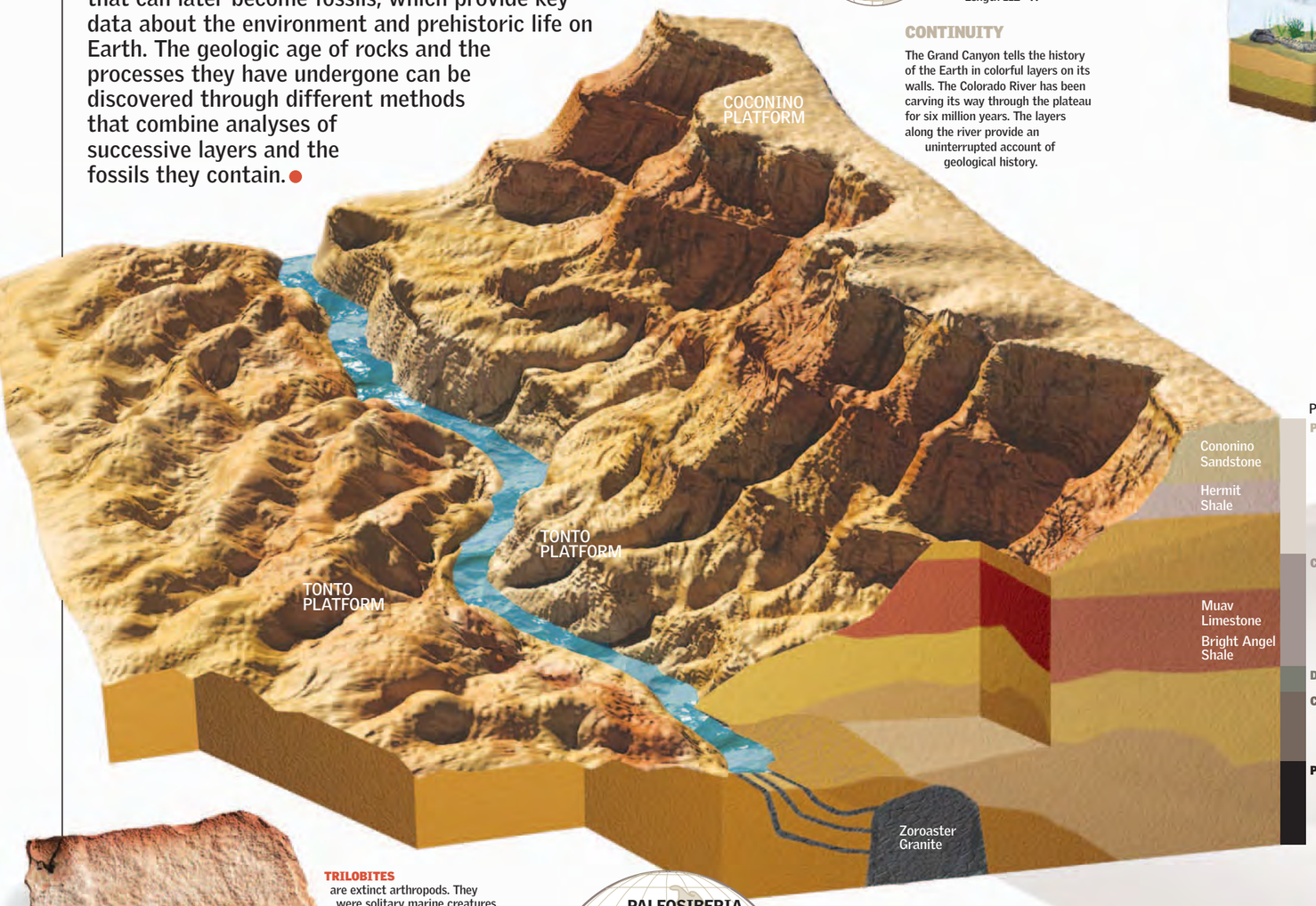
Isolated in a narrow strip of limestone from the Precambrian, in the highlands of Oudtshoorn, the Cango Caves are remarkable for their abundant deposits of calcite. They are left over from a larger channel below the water table. This channel dried up when the neighboring surface valleys were worn down to lower levels. The impressive stalagmites were then formed..

If Stones Could Speak

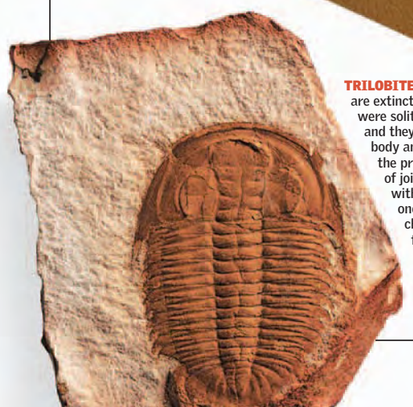
Rock strata form from sediments deposited over time in successive layers. Sometimes these sediments bury remains of organisms that can later become fossils, which provide key data about the environment and prehistoric life on Earth. The geologic age of rocks and the processes they have undergone can be discovered through different methods that combine analyses of successive layers and the fossils they contain.

GRAND CANYON
Colorado River
Arizona
Latitude 36° N
Length 112° W

CONTINUITY
The Grand Canyon tells the history of the Earth in colorful layers on its walls. The Colorado River has been carving its way through the plateau for six million years. The layers along the river provide an uninterrupted account of geological history.



Period
PERMIAN — Cononino Sandstone; Hermit Shale
CARBONIFEROUS — Muav Limestone; Bright Angel Shale
DEVONIAN
CAMBRIAN
PRECAMBRIAN



TRILOBITES
are extinct arthropods. They were solitary marine creatures, and they had a segmented body and an exoskeleton of the protein chitin, with pairs of jointed limbs. Together with graptolites they are one of the most characteristic fossils from Paleozoic marine sediments.

PRINCIPLE OF SUCCESSION
Fossils succeeded one another in a definite order, which makes it possible to date past events. The existence of identical fossils on different continents helps establish correlations and assigns the same age to widely separated geographic areas.

A Fossil's Age

Fossils are remains of organisms that lived in the past. Today scientists use several procedures, including carbon-14 dating, to estimate their age. This method makes it possible to date organic remains with precision from as long ago as 60,000 years. If organisms are older, there are other methods for absolute dating. However, within a known area, a fossil's location in a given sedimentary layer enables scientists to place it on an efficient, relative time scale. Following principles of original horizontality and of succession, it is possible to find out when an organism lived.

1. When it dies, an animal can be submerged on a riverbed, protected from oxygen. The body begins to decompose.

2. The skeleton is completely covered with sediments. Over the years, new layers are added, burying the earlier layers.

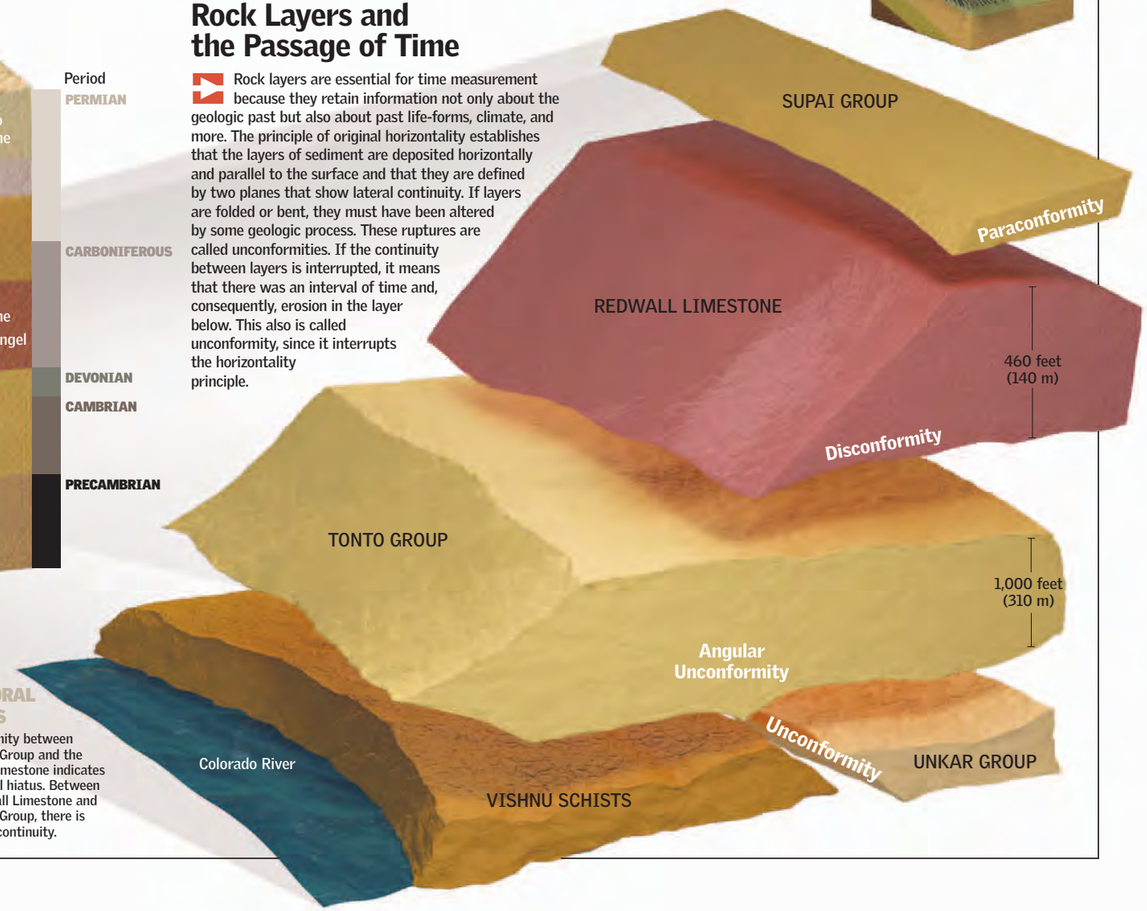
During fossilization, molecules of the original tissue are replaced precisely with minerals that petrify it.

3. Once the water disappears, the fossil is already formed and crystallized. The crust's movements raise the layers, bringing the fossil to the surface.

4. Erosion exposes the fossil to full view. With carbon-14 dating, scientists can determine if it is less than 60,000 years old.

Rock Layers and the Passage of Time

Rock layers are essential for time measurement because they retain information not only about the geologic past but also about past life-forms, climate, and more. The principle of original horizontality establishes that the layers of sediment are deposited horizontally and parallel to the surface and that they are defined by two planes that show lateral continuity. If layers are folded or bent, they must have been altered by some geologic process. These ruptures are called unconformities. If the continuity between layers is interrupted, it means that there was an interval of time and, consequently, erosion in the layer below. This also is called unconformity, since it interrupts the horizontality principle.



TEMPORAL HIATUS
Unconformity between the Tonto Group and the Redwall Limestone indicates a temporal hiatus. Between the Redwall Limestone and the Supai Group, there is temporal continuity.

Metamorphic Processes

When rocks are subjected to certain conditions (high pressure and temperature or exposure to fluids with dissolved chemicals), they can undergo remarkable changes in both their mineral composition and their structure. This very slow process, called metamorphism, is a veritable transformation of the rock. This phenomenon originates inside the Earth's crust as well as on the surface. The type of metamorphism depends on the nature of the energy that triggers the change. This energy can be heat or pressure.

570° F (300° C)

SLATE
Metamorphic rock of low grade that forms through pressure at about 390° F (200° C). It becomes more compact and dense.

930° F (500° C)

SCHIST
Very flaky rock produced by metamorphism at intermediate temperatures and depths greater than six miles (10 km). The minerals recrystallize.

1,200° F (650° C)

GNEISS
Produced through highly metamorphic processes more than 12 miles (20 km) beneath the surface, it involves extremely powerful tectonic forces and temperatures near the melting point of rock.

1,470° F (800° C)

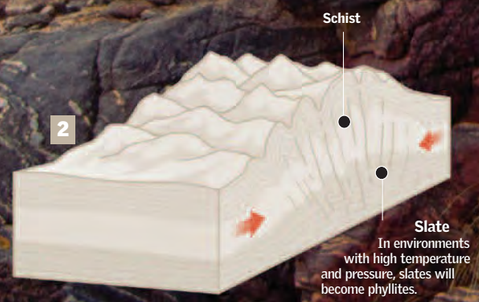
FUSION
At this temperature, most rocks start to melt until they become liquid.

SCOTLAND,
United Kingdom
Latitude 57° N
Longitude 04° W

Scotland was raised in the Caledonian orogeny 400 million years ago. This pressure produced the gneiss shown in the photo.

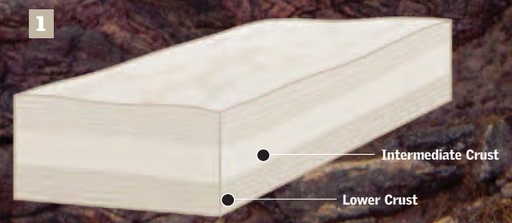
Dynamic Metamorphism

The least common type of metamorphism, dynamic metamorphism happens when the large-scale movement of the crust along fault systems causes the rocks to be compressed. Great rock masses thrust over others. Where they come in contact new metamorphic rocks, called cataclasites and mylonites, are formed.



Regional Metamorphism

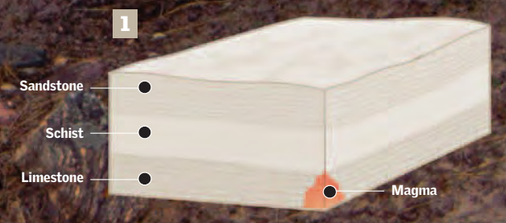
As mountains form, a large amount of rock is deformed and transformed. Rocks buried close to the surface descend to greater depths and are modified by higher temperatures and pressures. This metamorphism covers thousands of square miles and is classified according to the temperature and pressure reached. Slate is an example of rock affected by this type of process.



PRESSURE
As the pressure increases on the rocks, the mineralogical structure of rocks is reorganized, which reduces their size.

Contact Metamorphism

Magmatic rocks transmit heat, so a body of magma can heat rocks on contact. The affected area, located around an igneous intrusion or lava flow, is called an aureole. Its size depends on the intrusion and on the magma's temperature. The minerals of the surrounding rock turn into other minerals, and the rock metamorphoses.



TEMPERATURE
The closer the rock is to the heat source and the greater the temperature, the higher the degree of metamorphism that takes place.

The Basis of Life

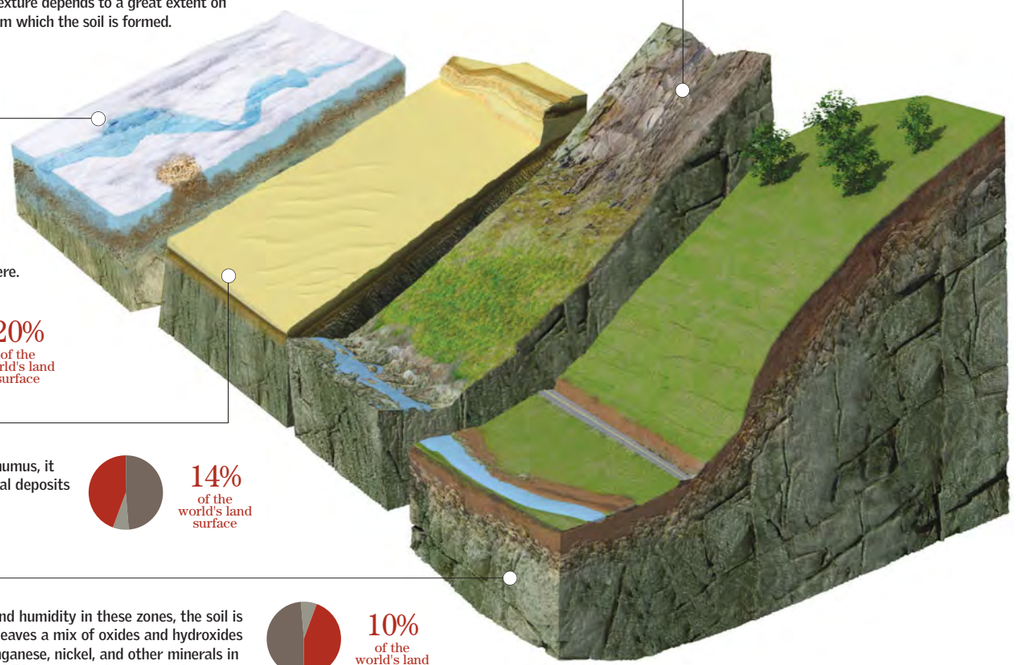
Organisms are born, live, reproduce, and die on a natural layer of soil. From this layer, crops are harvested, livestock are raised, and construction materials are obtained. It establishes the link between life and the mineral part of the planet. Through the action of climate and biological agents, soil forms where rocks are broken down.

300 years

The time needed for the natural formation of soil with its three basic layers, or horizons.

Types of Soil

In the soil we find bedrock materials that have been greatly altered by air and water, living organisms, and decomposed organic materials. The many physical and chemical transformations that it undergoes produce different types of soil, some richer in humus, other with more clay, and so on. The soil's basic texture depends to a great extent on the type of bedrock from which the soil is formed.



PERMAFROST
Areas near the poles
The soil is saturated with frozen water. In the parts that thaw, big puddles are formed. Because of its characteristics, many animals cannot live there.

20% of the world's land surface

DESERTIC
Arid soil
Containing very little humus, it rests directly on mineral deposits and rock fragments.

14% of the world's land surface

LATERITE
Typical tropical soil
With abundant rains and humidity in these zones, the soil is well drained. The rain leaves a mix of oxides and hydroxides of aluminum, iron, manganese, nickel, and other minerals in the soil. This represents 70 percent of the world's iron reserves.

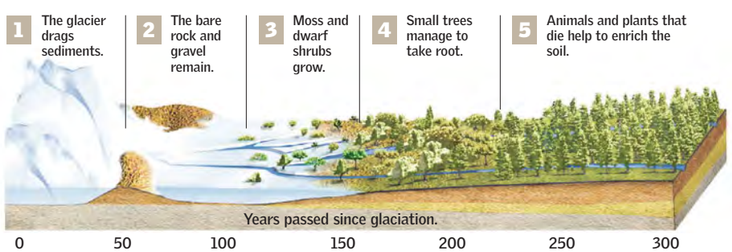
10% of the world's land surface

RANKER
develops on top of slightly altered bedrock. It is typical in high mountains, especially if it forms on granite or other acidic rocks.

0.2% of the world's land surface

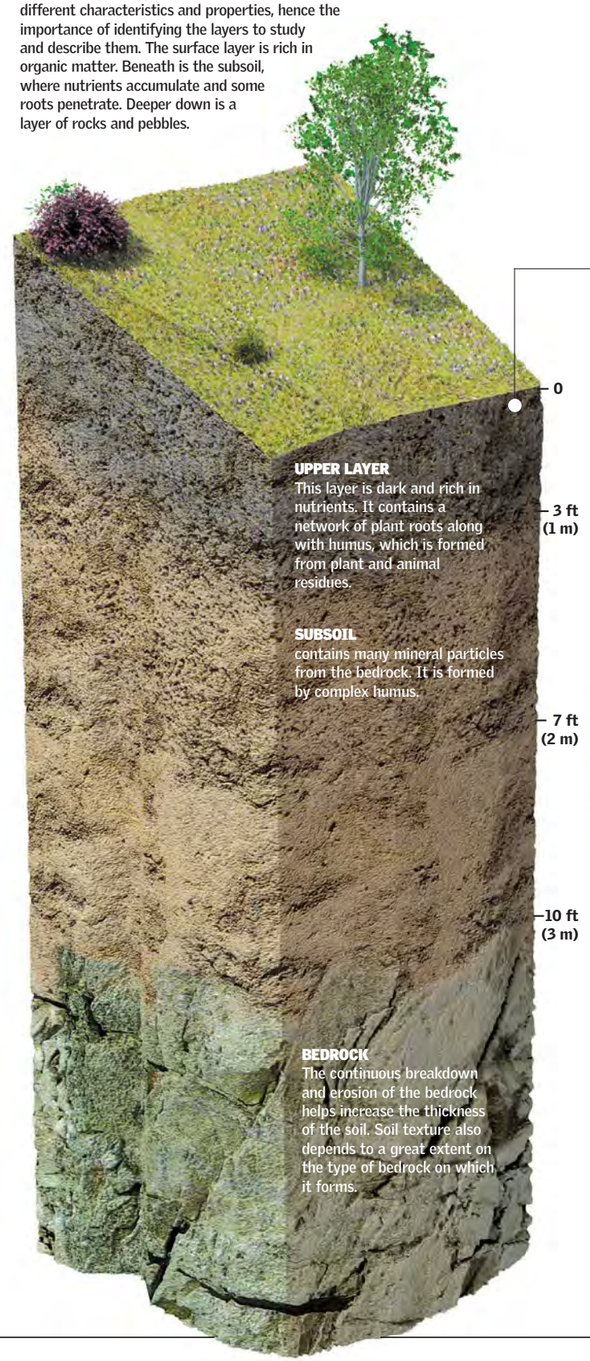
HOW IT FORMS

Much of the Earth's crust is covered with a layer of sediment and decomposing organic matter. This layer, called soil, covers everything except very steep slopes. Although it is created from decomposing plant and animal remains, the soil is a living and changing system. Its tiniest cavities, home to thousands of bacteria, algae, and fungi, are filled with water or air. These microorganisms speed up the decomposition process, turning the soil into a habitat favorable to plant roots as well as small animals and insects.



Different Characteristics

Observing the soil profile makes it possible to distinguish layers called horizons. Each layer has different characteristics and properties, hence the importance of identifying the layers to study and describe them. The surface layer is rich in organic matter. Beneath is the subsoil, where nutrients accumulate and some roots penetrate. Deeper down is a layer of rocks and pebbles.



UPPER LAYER
This layer is dark and rich in nutrients. It contains a network of plant roots along with humus, which is formed from plant and animal residues.

SUBSOIL
contains many mineral particles from the bedrock. It is formed by complex humus.

BEDROCK
The continuous breakdown and erosion of the bedrock helps increase the thickness of the soil. Soil texture also depends to a great extent on the type of bedrock on which it forms.

Living Organisms in the Soil

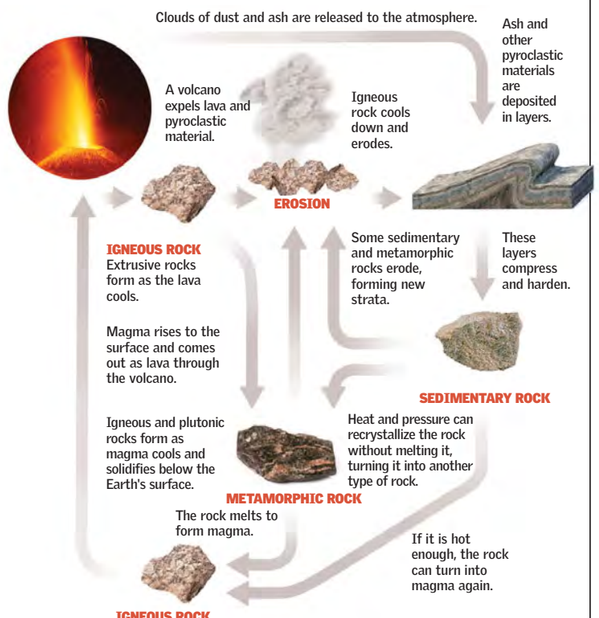
Many bacteria and fungi live in the soil; their biomass usually surpasses that of all animals living on the surface. Algae (mainly diatoms) also live closest to the surface, where there is most light. Mites, springtails, cochineal insects, insect larvae, earthworms, and others are also found there. Earthworms build tunnels that make the growth of roots easier. Their droppings retain water and contain important nutrients.

EARTHWORMS
It takes approximately 6,000 earthworms to produce 3,000 pounds (1,350 kg) of humus.

HUMUS
is the substance composed of organic materials, usually found in the upper layers of soil. It is produced by microorganisms, mainly acting on fallen branches and animal droppings. The dark color of this highly fertile layer comes from its high carbon content.

Rock Cycle

Some rocks go through the rock cycle to form soil. Under the action of erosive agents, rocks from the Earth's crust take on characteristic shapes. These shapes are a consequence partly of the rock's own composition and partly of several effects caused by erosive agents (meteorological and biological) responsible for breaking down rocky material.



Divine and Worshiped

Formed millions of years ago, some rocks enjoy the privilege of being considered deities. Pagans, Christians, Muslims, and Aborigines of Australia base part of their beliefs on the myths, properties, or legends of a rock. Among the best known are Uluru (Ayers Rock), the Black Stone located in the cube-shaped sepulcher of the Ka`bah, and the rocks of Externsteine, a destination of Christian pilgrimages and a sacred site for many ancient pagan religions. Their origins are described and studied in theology as well as in geology. Resistant to the passing of time, they are transformed into myths that remain to the present.

Beliefs

Each crack, protuberance, or groove of a rock has meaning to Aborigines. For example, a rock's orifices symbolize the eyes of a dead enemy.

Uluru

Sacred place for Australian Aborigines for thousands of years, Uluru (Ayers Rock) is four miles (9.5 km) in circumference and rises 1,100 feet (340 m) above the Australian desert. Uluru was discovered by Caucasians in 1872 and renamed Ayers Rock in honor of the Australian Prime Minister Henry Ayers. In this enormous sandstone mass, dozens of dream paths traversed by the Aborigines and the paths already traveled by their ancestors in the past converge through a series of myths. In this manner, all the sacred places are connected. On the rock are forms such as Kuniya women and the wounded head of the Liru warrior, among others.

ULURU-KATA TJUTA NATIONAL PARK, Australia

Latitude 25° S
Longitude 131° E

The great reddish rock of Uluru was created during the Alice Springs orogeny, 400 million years ago. The sandstone and conglomerates that formed the ancient alluvial fans folded and fractured deeply, turning horizontal layers on their ends.

CAVE PAINTINGS

Uluru contains some of the most representative features of the ancestral history of the Aborigines. The caves surrounding the base of the rock have some Aboriginal paintings illustrating the paths and limits of the Dream Time. Many carvings in the caves are considered to be of divine origin.

100 feet
(30 m)

the height of the Externsteine formation. It consists of five limestone pillars, riddled with caves, passages, and secret chambers.

Externsteine

Made of oddly twisted limestone rocks, Externsteine is located in the Teutoburg Forest north of the Rhine River in Rhineland, Germany. It was the place of heroic myths and German legends. It is also related to the Scandinavian Eddas and, during Nazism, to the Aryan myth. According to popular belief, the stones were placed there at night by giants; they were then burned by the devil, which explains their grotesque appearance.

MUSLIM TRADITION

Muslims who have the necessary means are expected to go to Mecca at least once in their lives.

The Black Stone of the Ka`bah

Located in one corner of the Ka`bah, the Black Stone is the most sacred treasure of the Islamic world. The Ka'bah is a cubic building located in Mecca, toward which Muslims face as they pray five times a day. The stone's exposed surface is 6 x 8 inches (16 x 20 cm), and its pieces are held together by a frame with a silver band. Muslims relate its origin to Adam and say that Abraham and his son Ishmael built the Ka`bah, but it was the Prophet Muhammad who converted Mecca into the sacred center of Islam in the 7th century.

Classes of Rocks

BEAUTIFUL AND STRANGE
The inside of a geode, a rock filled with crystals, usually displays a beautiful formation.

HOW TO IDENTIFY ROCKS 62-63
IGNEOUS ROCKS 64-65
MARINE SEDIMENTS 66-67
COLLECTION OF DETRITAL ROCKS 68-69
ORGANIC ROCKS 70-71
COMMON METAMORPHIC ROCKS 72-73
INCREDIBLE PETRA 74-75

Different types of rocks can be distinguished based on their luster, density, and hardness, among other properties. A geode looks like a common rock on the outside, but when it is cut in half, a fantastic range of colors and shapes can be revealed. The several classes of rocks can also be grouped according to how they formed, giving us the categories of igneous, metamorphic, and sedimentary rocks. Most characteristics of rocks depend on their constituent minerals. There are also organic rocks, formed through the accumulation of the remains of organisms that decomposed millions of years ago. Coal and some types of carbonate and siliceous rocks are part of this group. ●

How to Identify Rocks

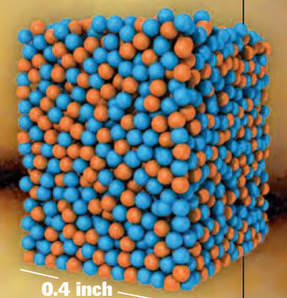
Rocks can be classified as igneous, metamorphic, or sedimentary according to the manner in which they were formed. Their specific characteristics depend on the minerals that constitute them. Based on this information, it is possible to know how rocks gained their color, texture, and crystalline structure. With a little experience and knowledge, people can learn to recognize and identify some of the rocks that they often see.

Color

The color of a rock is determined by the color of the minerals that compose it. Some colors are generated by the purity of the rock, whereas others are produced by the impurities present in it. Marble, for instance, can have different shades if it contains impurities.

WHITE
If the rock is a marble composed of pure calcite or dolomite, it is usually white.

BLACK
Various impurities give rise to different shades in the marble.



Shapes

The final shape that a rock acquires depends to a great extent on its resistance to outside forces. The cooling process and subsequent erosion also influence the formation of rocks. Despite the changes caused by these processes, it is possible to infer information about a rock's history from its shape.

ANGULAR
Rocks have this shape when they have not been worn down.

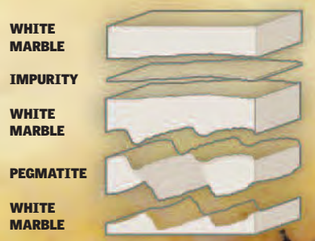
ROUNDED
The wear caused by erosion and transport gives rocks a smooth shape.

Age

Being able to accurately determine the age of a rock is very useful in the study of geology.

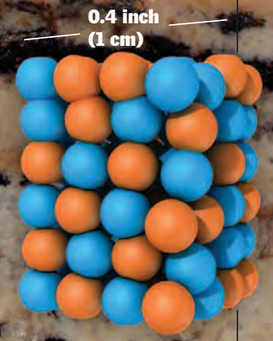
Fracture

When a rock breaks, its surface displays fractures. If the fracture results in a flat surface breaking off, it is called exfoliation. Rocks usually break in locations where their mineral structure changes.



Texture

refers to the size and arrangement of grains that form a rock. The grains can be thick, fine, or even imperceptible. There are also rocks, such as conglomerates, whose grains are formed by the fragments of other rocks. If the fragments are rounded, there is less compaction, and the rock is therefore more porous. In the case of sedimentary rocks in which the sedimentary cement prevails, the grain is finer.



GRAIN
is the size of the individual parts of a rock, be they crystals and/or fragments of other rocks. A rock's grain can be thick or fine.

Mineral Composition

Rocks are natural combinations of two or more minerals. The properties of rocks will change in accordance with their mineralogical composition. For instance, granite contains quartz, feldspar, and mica; the absence of any of these elements would result in a different rock.

CRYSTALS
form when a melted rock cools and its chemical elements organize themselves. Minerals then take the shape of crystals.

Igneous Rocks

Formed from magma or lava, igneous rocks can be classified according to their composition. This classification specially takes into account: the relative proportion of silica, magnesium, and iron minerals found in these type of rocks; their grain size (which reveals how fast they cooled); and their color. Rocks that contain silica, along with much quartz and feldspar, tend to have pale colors; those with low silica content have dark colors created by iron and magnesium-containing minerals, such as olivine, pyroxene, and amphiboles. A rock's texture is determined by the configuration of its crystal grains.

Underground: Plutonic or Intrusive Rocks

Rocks of this type formed through the solidification of magma masses deep within other rocks. In general, they have undergone a slow cooling process in the Earth's crust, which has permitted the formation of pure mineral crystals large enough to be seen with the unaided eye. Usually they display a compact structure and have low porosity. Depending on the composition of the magma, there are acidic plutonic rocks (rich in silicon) or basic rocks (with low silicon content). Granite is the most common type of intrusive rock.

MACROPHOTOGRAPHY OF PINK GRANITE

GRANITE

This rock is formed by big grains of feldspar, quartz, and mica. Its light-colored components indicate an abundance of silicon and that the rock is acidic. Because of its great resistance to wear, granite is often used as a construction material.

1 mile (1.6 km)

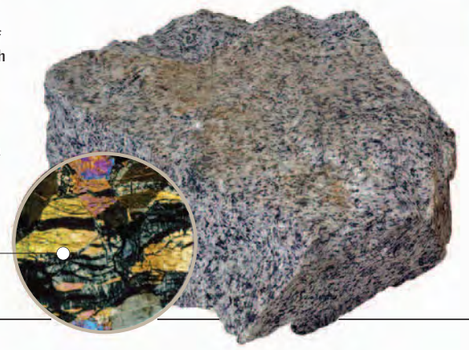
THE MINIMUM DEPTH AT WHICH GRANITE FORMS

GABBRO

This rock contains ferromagnesian minerals, such as olivine, pyroxene, and augite, which form dark-colored crystallizations, and feldspars, which give a white coloring to some of its parts. Gabbro generally solidifies slowly, leaving it with thick grains.

PERIDOTITE

This rock is mainly composed of olivine (which gives it a greenish color) and pyroxene. It is less than 45 percent silicon and is rich in magnesium, a very light metal. It is abundant in the upper layers of the mantle (at a depth of about 40 miles [60 km]) as a residue of old crust.



MACROPHOTOGRAPHY OF GRANODIORITE

GRANODIORITE

This rock is often confused with granite, but it is grayer since it contains larger numbers of quartz and sodic plagioclase crystals than it does feldspar. It has thick grains and contains dark crystals called nodules.

Dikes and Sills: Rocks Formed in Seams

Some types of igneous rocks are formed from ascending magma that solidifies in seams or fissures. The resulting sheetlike body of rock is called a dike if it has a vertical orientation or a sill if it has a horizontal orientation. The composition of these rocks is similar to those of intrusive and extrusive rocks. In fact, like dikes and sills, intrusive and extrusive rocks can also form in cracks. However, the manner in which the materials in a sill or dike solidify causes them to form crystalline structures different from those of their volcanic and plutonic relatives.

PEGMATITE IS NATURALLY SMOOTH.

PEGMATITE

This very abundant, acidic rock has a mineral composition identical to that of granite. However, its solidification process was very slow, thus enabling its crystals to grow to a size of several feet.

CRYSTAL JOINED BY VITREOUS MASS

PORPHYRITICS

These rocks solidify in two phases. In the first, slower phase, thick phenocrystals form. Then in the second phase, the phenocrystals are dragged along by magma, which causes the formation of smaller, vitreous crystals. The name porphyritic alludes to the color purple.

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PEGMATITE IS ASSOCIATED WITH THE PRESENCE OF GEMS AND RARE METALS.

Extrusive Rocks, Products of Volcanoes

Extrusive rocks form through the fast cooling of magma on or near the Earth's surface. Their structure and composition are closely related to the volcanic activity in the areas where they emerge. Because they are typically products of a fast solidification process, they usually have a very fine grain. When they are expelled from a volcano, they do not have a chance to crystallize before they cool, so they acquire a vitreous (glasslike) texture.

PUMICE

This rock is produced from lava with a high silicon and gas content, which gives it a foamy texture. This explains its porous consistency—acquired during rapid solidification—which enables it to float in water.

OBSIDIAN

This rock is black; its shades vary in accordance with its impurities. Because it undergoes rapid cooling, its structure is vitreous, not crystalline; thus, it is commonly called volcanic glass. Strictly speaking, obsidian is a mineraloid. It was often used to make arrowheads.

BASALT

This rock forms most of the oceanic crust. Its low silicon content gives it its characteristic dark color (between blue and black). Its rapid cooling and solidification gives it a very fine grain. Because of its hardness, it is used to build roads; it is not, however, used to make paving stones because it is too slippery.

GEOMETRIC PRISMS

These prisms were formed in the Giant's Causeway (Northern Ireland) through contraction, expansion, and rupture of basaltic lava flows that crystallized gradually.

Hexagon

THE MOST COMMON SHAPE INTO WHICH BASALT CRYSTALLIZES

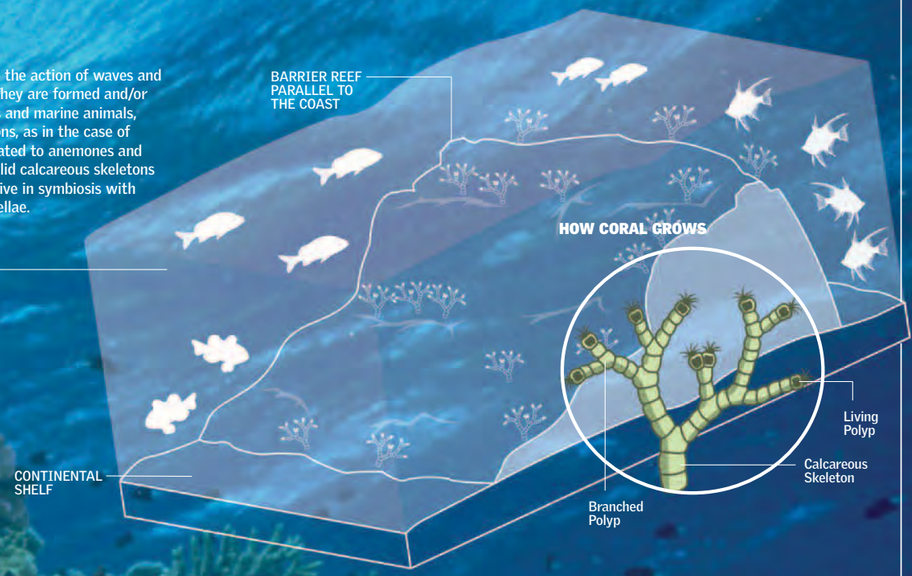
Marine Sediments

Sedimentary rocks can also form through the accumulation and lithification of organic remains. The most common example is coral reefs, which develop underwater, surrounding the coasts of many temperate seas. Many limestone rocks also originate this way; they are made of calcium carbonate (calcite) or calcium and magnesium (dolomite). Because of their porous consistency, they often serve as repositories for fossil fuels, which are also of organic origin. Other rocks, like coquina, form through the accumulation of fragments of marine shells, lithified over time as materials filled and cemented their interstices.

68° F (20° C)
MINIMUM WATER TEMPERATURE NEEDED FOR THE FORMATION OF CORAL REEFS

Coral Reefs

are rocky structures resistant to the action of waves and to the movement of the water. They are formed and/or colonized by photosynthetic organisms and marine animals, some of which have calcareous skeletons, as in the case of coral polyps. These soft organisms, related to anemones and jellyfish, live in colonies. When their solid calcareous skeletons sediment, they turn into calcite. They live in symbiosis with single-celled algae known as zooxanthellae.

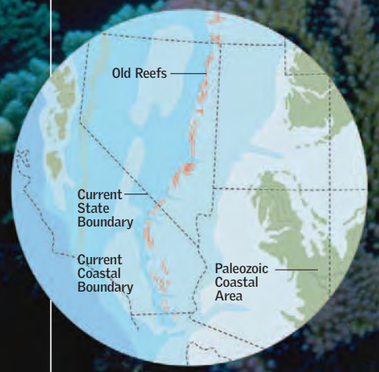


FROM SEDIMENT TO ROCK
Under pressure from overlying layers, sediments are compacted and lithified, reducing their volume by 40 percent. Other substances dissolved in water (calcite, silica, and iron oxide) fill up the interstices between the particles of sediments, and when the water evaporates, cementation occurs.

BRANCH CORAL

BRAIN CORAL

CORALS IN ARIZONA
In the first phase of the Paleozoic Era (500 million years ago), the current mountainous region of the American West was a coastal area with much coral activity. This is how the abundant calcareous formations that can be seen today in Arizona's Grand Canyon originated. These formations also coexist with much younger rocks.



FLAT CORAL
Corals typically grow in colonies and create reefs, layer by layer.

3 feet (1 m)
THE HEIGHT THAT A REEF CAN GROW TOWARD THE SURFACE IN ONE YEAR

Pearl, Jewel of the Sea

In order to protect themselves from the intrusion of a foreign body—such as a sand grain that becomes lodged between their mantle and shell—bivalve mollusks cover the intruding object with alternating concentric layers of protein (conchiolin) and calcite. This process ultimately yields a pearl. Fine pearls are produced by pearl oysters (Pinctada) in the warm, clear waters of tropical seas.

Collection of Detrital Rocks

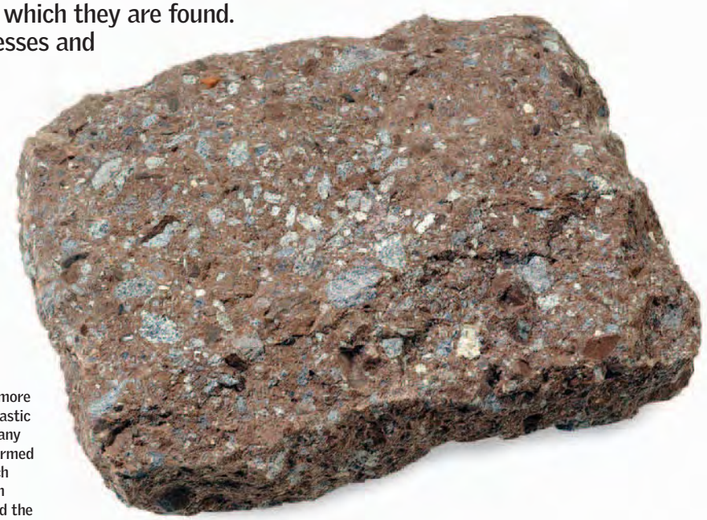
Among the sedimentary rocks, detrital rocks are the most abundant. They form through the agglomeration of rounded fragments (clasts) of older rocks. Depending on the size of the clasts, they are classified as (from smallest to largest) pelite, lutite and limestone, sandstone, and conglomerates. The analysis of their components, cementation matrix, and arrangement in layers makes it possible to reconstruct the geologic history both of the rocks and of the areas in which they are found. Some break off easily and are used in industrial processes and construction as rock granules, whereas others are appreciated for their toughness and hardness.

Clay, Lime, and Ash

These materials form the less porous, fine-grained detritic rocks. Lutites are rocks of clay, composed of particles whose diameter does not exceed 0.0002 inch (0.004 mm). In general, they are compacted and cemented through chemical precipitation. Limestone rocks are also called limolites, named after lime, a sedimentary material with a somewhat thicker grain (up to 0.0025 inch [0.06 mm]). Some rocks composed of volcanic ash have a similar granulation. These rocks are very important in construction.

COMPACTED ASH
It is possible to find one or more layers of fine-grained pyroclastic material (volcanic ash) in many sedimentary rocks. Rocks formed from larger pyroclasts, which solidified in the air during an eruption before they touched the ground, are rarer. Their origin is igneous, but their formation is sedimentary.

40%
THE REDUCTION IN THE VOLUME OF CLAY AS IT IS COMPACTED



TUFF
is rock that is formed from deposits of volcanic ash that has been cemented together. There are several types: crystalline tuff, which is largely composed of igneous glass; lithic tuff, which contains rock fragments; and hybrid tuff, which is formed from fragmented volcanic material combined with some clay.

CLAY (KAOLINITE)
When hydrated, it increases in size.

CLAY
The substance commonly known as clay is an unconsolidated rock, made of hydrated aluminum silicates and typically full of impurities. Kaolin is the name for pure granular clay; it is soft and white and keeps its color even after it has been fired in a kiln. It has scale-shaped microcrystals and generally contains impurities.

CHALK
Composed of calcite debris of biochemical origin, this mineral originates in the sea near the coast. After being eroded and transported, it accumulates on slopes where it becomes compacted. The chalk we use on blackboards is, in reality, gypsum.

COMPACTED
Very fine sediment

A Variety of Sandstones

Sandstone is rock composed of grains that are mostly between 0.003 and 0.08 inch (0.06 and 2 mm) in size. Sandstones are classified according to their mineral composition, their level of complexity (or geologic history), and the proportion of cementation material they contain. Quartzarenite (which is more than 95 percent quartz), arkose (which is mostly feldspar), red sandstone (which is cemented by iron compounds), and graywacke belong to this class of rocks.

SANDSTONE
is made up of small grains of sand that are here stratified by color and texture. This type of sandstone indicates that an alternating process of sedimentation involving two types of particles has occurred.

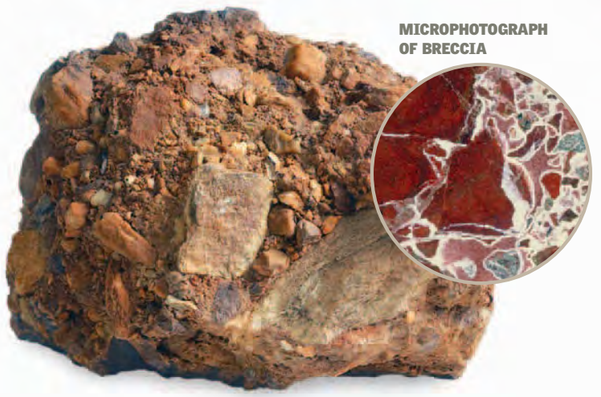
ARKOSE
possesses a varied composition, although it contains up to 25 percent quartz and feldspar. Generally, it has a porous consistency, and less than one percent of its interstices are empty. In this specimen, the pinkish section is composed of feldspar, and the white portion is quartz.

GRAYWACKE
has a defined proportion of calcium carbonate, quartz, feldspar, and mica. It differs from common sandstone because it contains a higher amount of cementation materials (more than 15 percent), which form its grain matrix. This makes it more compacted.

20%
OF SEDIMENTARY ROCKS ARE SANDSTONES.

Conglomerates

Most of the grains that compose these rocks are larger than 0.08 inch (2 mm). In some cases, it is possible to identify with the unaided eye the primary rocks from which a conglomerate is formed. As a result, it is possible to determine the areas where the sediments originated. Accumulations of gravel and cementation material can indicate either slopes in the rocks where the conglomerates formed or the action of fluvial currents. All this information makes it possible to reconstruct the geologic history of a rock.



MICROPHOTOGRAPH OF BRECCIA

CONGLOMERATE
Formed by large fragments, they are good examples of sediments that have been compacted after landslides. The irregularity of this specimen's clasts points to a chaotic origin, which could be alluvial in nature or associated with a glacial moraine.

85%
PERCENTAGE OF CLASTS LARGER THAN 0.08 INCH (2 MM)

BRECCIA
Its grains are thick but with straight angles and edges. This shows that the sediments have not traveled far and that cementation has taken place near the area from which the materials originated.

Organic Rocks

Organic rocks are composed of the remains of living organisms that have undergone processes of decomposition and compaction millions of years ago. In these processes, the greater the depth and heat, the greater the caloric power and thermal transformation of the rock. The change experienced by these substances is called carbonization.

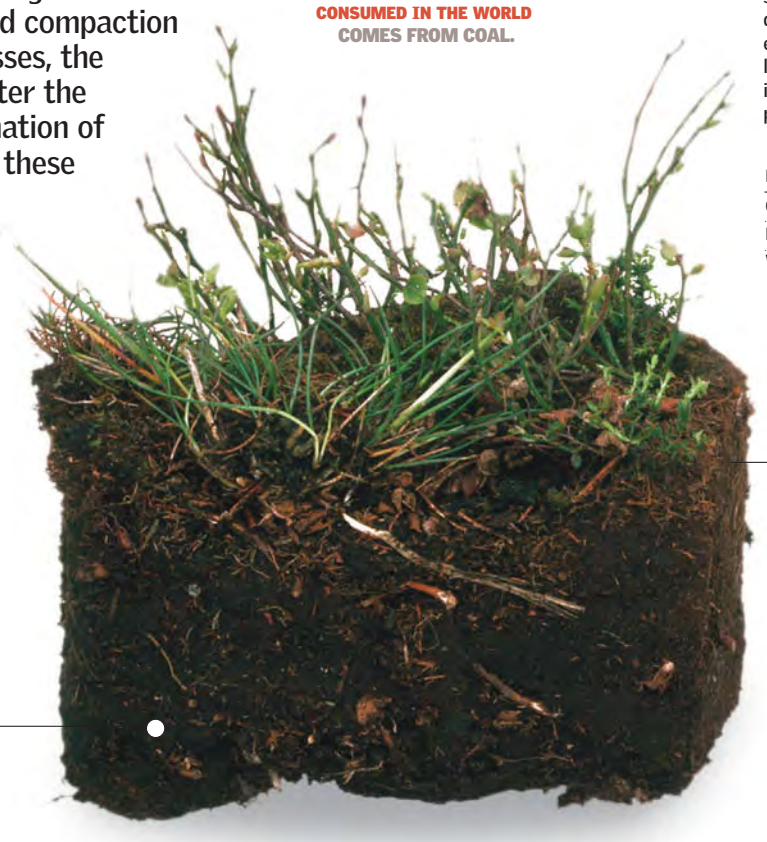
26%

OF THE PRIMARY ENERGY CONSUMED IN THE WORLD COMES FROM COAL.

Coal Formation

Plant materials, such as leaves, woods, barks, and spores, accumulated in marine or continental basins 285 million years ago. Submerged in water and protected from oxygen in the air, this material slowly became enriched with carbon through the action of anaerobic bacteria.

Transformation of Vegetation into Hard Coal



1. Vegetation

Organic compounds on the surface became covered by oxygen-poor water found in a peat bog, which effectively shielded them from oxidation.

2. Peat

Through partial putrefaction and carbonization in the acidic water of the peat bog, the organic matter changes into coal.

Contains 60% carbon

3. Lignite

is formed from the compression of peat that is converted into a brown and flaky substance. Some primary plant structures can still be recognized in it.

Contains 70% carbon

4. Coal

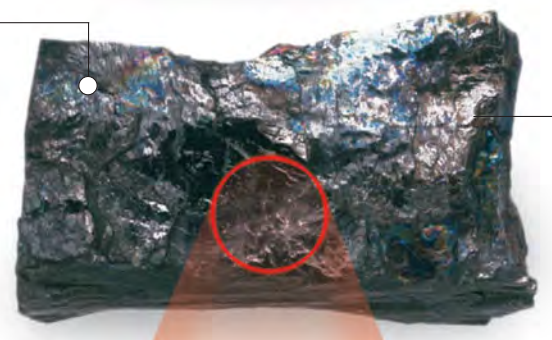
has a content of less than 40 percent mineral substance on the basis of dry material. It has a matte luster, is similar to charcoal, and is dirty to the touch.

Contains 80% carbon

5. Anthracite

is the type of coal with the greatest concentration of carbon. Its high heat value is mostly due to this type of coal's high carbon content and low concentration of volatile material. It is harder and denser than ordinary coal.

Contains 95% carbon



ANTHRACITE ROCK

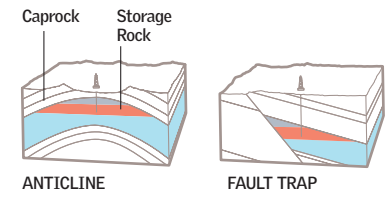
At times, the surface of anthracite can appear to have traces of plant fossils.

FORMATION OF PETROLEUM

In an anaerobic environment at a depth of about 1 mile (2 km), organic sediments that developed in environments with little oxygen turn into rocks that produce crude oil.

KEY
- Gas
- Petroleum (Oil)
- Water

PETROLEUM TRAPS



LOCATION INSIDE THE EARTH

Vegetation that will form peat after dying

Peat is compacted and transformed.

Coal rich in humic acids

Coal: gas and fuel is obtained

Metamorphism where gases and oils are released

The movements of the Earth's crust subjected the strata rich in organic remains to great pressure and transformed them into hard coal over the course of 300 million years.

SURROUNDING TEMPERATURE

LEGEND
- Exerted Pressure.

DEPTH
up to 1,000 feet
(300 m)

TEMPERATURE
up to 77° F
(25° C)

DEPTH
1,000 to 5,000 feet
(300 to 1,500 m)

TEMPERATURE
up to 104° F
(40° C)

DEPTH
5,000 to 20,000 feet
(1,500 to 6,000 m)

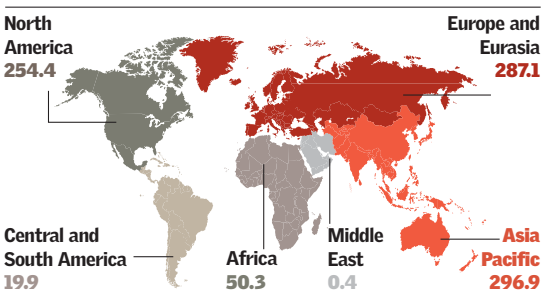
TEMPERATURE
up to 347° F
(175° C)

DEPTH
20,000 to 25,000 feet
(6,000 to 7,600 m)

TEMPERATURE
up to 572° F
(300° C)

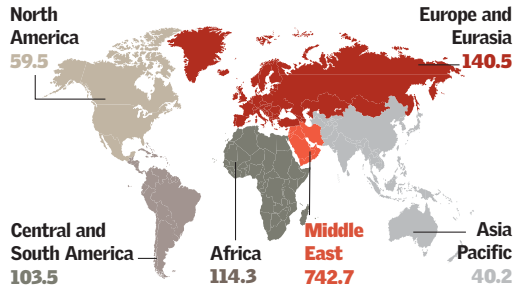
WORLD COAL RESERVES

Billions of tons



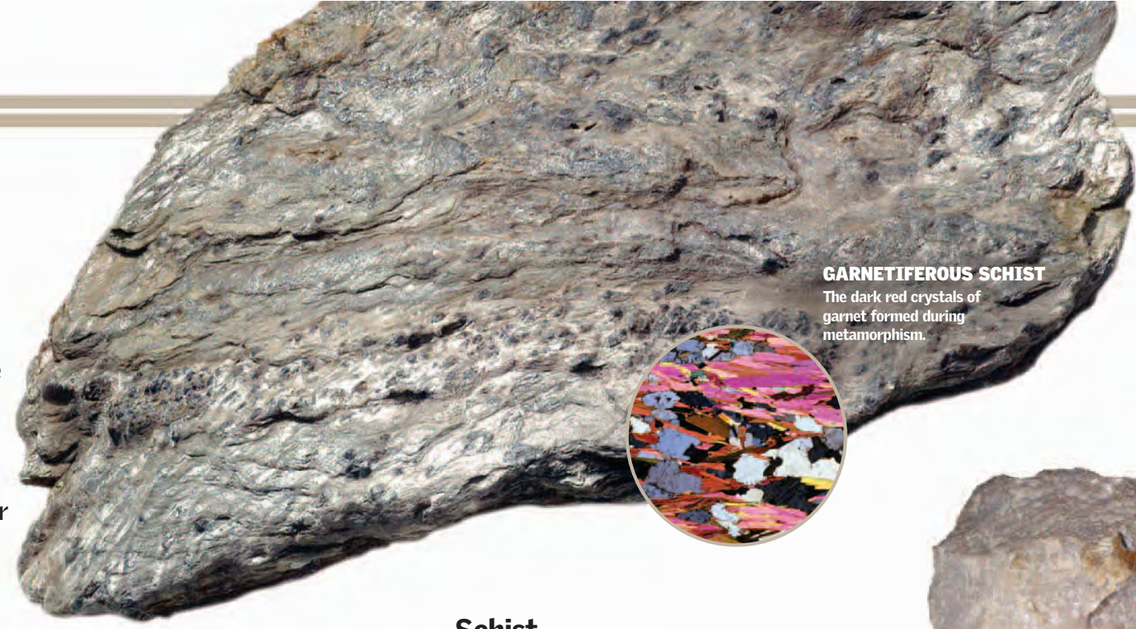
WORLD PETROLEUM RESERVES

Billions of barrels



Common Metamorphic Rocks

The classification of metamorphic rocks is not simple because the same conditions of temperature and pressure do not always produce the same final rock. In the face of this difficulty, these rocks are divided into two large groups, taking into account that some exhibit foliation and others do not. During the transformation process, the density of rock increases, and recrystallization can induce the formation of bigger crystals. This process reorganizes the mineral grains, resulting in laminar or banded textures. Most rocks derive their color from the minerals of which they are composed, but their texture depends on more than just their composition.



GARNETIFEROUS SCHIST
The dark red crystals of garnet formed during metamorphism.

Marble and Quartzite

These rocks are compacted and nonfoliated. Marble is a thick-grained crystalline rock, derived from limestone or dolostone. Because of its color and toughness, marble is used in the construction of large buildings. Quartzite is a very hard rock, usually made of sandstone rich in quartz, which, under elevated metamorphic conditions, melts like pieces of glass. Quartzite is normally white, but iron oxide can give it a reddish or pinkish tone.

7 IS THE LEVEL OF HARDNESS OF QUARTZITE.

QUARTZITE
It is hard and tough; it is compacted because the quartz grains entwine.

SLATE
Its black color comes from the carbon in organic matter present in sediments.

SLATE MICROGRAPHY
Composed of foliated or laminated clay minerals

Slates and Phyllites

These foliated rocks recrystallized under moderate pressure and temperature conditions. Slate has very fine grains made of small mica crystals. It is very useful in the production of roof tiles, floor tiles, blackboards, and billiard tables. It almost always is formed through low-grade metamorphism in sediments and, less often, from volcanic ash. Phyllite represents a gradation in metamorphism between slate and schist; it is composed of very fine mica crystals, such as muscovite or chlorite.

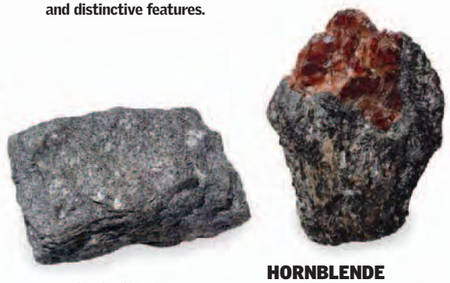
PHYLLITE
Similar to slate, it is notable for its silky luster.

SLATE
Because of exfoliation, it tends to break into flat sheets.

Foliation

LAMINATED OR STRIPED TEXTURE, RESULTING FROM THE PRESSURE TO WHICH THE ROCK WAS SUBJECTED

GARNETIFEROUS SCHIST
This rock's name comes from its components. Schist determines its texture and garnet its color and distinctive features.



MICACEOUS SCHIST
Its characteristic coloring is determined by colorless or white muscovite crystals.

HORNBLENDE SCHIST
It contains some sodium as well as considerable amounts of iron and aluminum.

Gneiss

Striped rock that usually contains long and granular minerals. The most common types are quartz, potash feldspar, and plagioclase. It can also have smaller amounts of muscovite, biotite, and hornblende. Its characteristic stripes are due to a segregation of light and dark silicates. Gneiss rock, which has a mineral composition similar to that of granite, is formed through sedimentary processes or derived from igneous rocks. However, it can also form through high-grade metamorphism of schists. It is the last rock of the metamorphic sequence.

Stripes

MAKE IT POSSIBLE TO DETERMINE THE DIRECTION IN WHICH PRESSURE WAS EXERTED ON THE ROCK.

Schist

This rock is more prone to foliation, and it can break off in small sheets. It is more than 20 percent composed of flat, elongated minerals, which normally include mica and amphiboles. For schist to be formed, a more intense metamorphism is needed. The different schistose rocks' names and characteristics depend on the predominant mineral that composes them or on the one that produces exfoliation. Among the most important schistose rocks are mica, hornblende, and talc. Because this type of rock has different layers, it has been used in sculpture.

0.04 inch (1 mm)

OR MORE. THE SIZE OF MICA GRAINS IN SCHIST—LARGE ENOUGH TO SEE WITH THE UNAIDED EYE.

GNEISS
Heat and pressure can change granite into gneiss.

MARBLE
It is highly valued for its texture and color. It is used in sculpture and architecture.

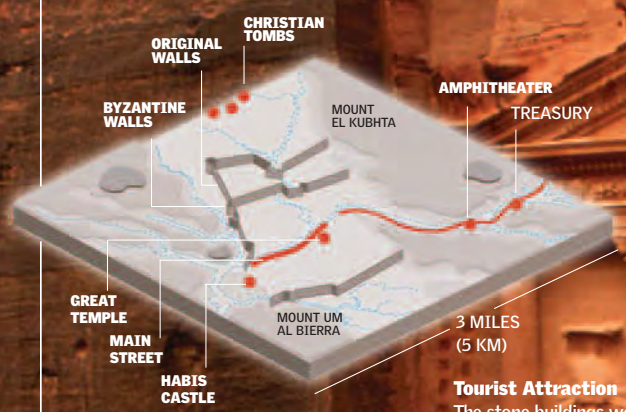
MARBLE MICROGRAPH
Impurities and accessory minerals color the marble.

Incredible Petra

Historians from ancient Rome used to talk about a mysterious city of stone. In 1812 Johann Ludwig Burckhardt of Switzerland rediscovered it. Traces of Neolithic civilizations were found in Petra; however, its foundation in the 4th century BC is attributed to the Nabataeans, a nomadic people. The Nabataeans were merchants and raiders who became prosperous by controlling the spice trade. The city, carved in sandstone, knew times of splendor, but it eventually fell into ruin.

Temples and Tombs

The only way to reach Petra is by foot through a narrow passage among the rocks. The passage is 1 mile (1.5 km) long and, at some points, less than 3.3 feet (1 m) wide. The Treasury (Khasneh) is the first seen upon entering the city, followed by a Roman amphitheater. The buildings are carved into cliffs, and more than 3,000 old tombs have been excavated. The city also has fortifications.



Tourist Attraction
The stone buildings were erected at different times over a period of 1,000 years.

HIDDEN IN THE DESERT

Petra is hidden in the mountains 155 miles (250 km) south of Amman, the capital of Jordan, and north of the Red Sea and the Great Rift Valley in Africa.

On the Rift

ITS CLIFFS ARE PART OF THIS FRACTURE; IN THE YEAR 363, IT WAS DAMAGED BY AN EARTHQUAKE.

Uncertain Origins

Petra's architecture is dominated by Greek, Egyptian, and Roman features; however, their symbiosis with Eastern elements is so great that to this day experts find it difficult to establish Petra's origin and dates of construction. The city's exterior adornments contrast with the interior sobriety of its temples. It contained sumptuous public baths that date from a time of splendor (1st century BC). However, most of Petra's population, which reached a peak of 20,000 inhabitants, lived in adobe houses.

ELEPHANTS (Interpretation)
Native to Africa or India, elephants were not represented in classic culture. Here, however, they are seen adorning Greek-style capitals. This particular merging of cultures created expressions found nowhere else in the ancient world. Archaeologists find it difficult to date the pieces of art found in Petra.

The Treasury

IT WAS BELIEVED THAT THIS BUILDING HOUSED A PHARAOH'S TREASURE. ITS CUBE-SHAPED INTERIOR HAS SMOOTH WALLS AND IS LINED WITH MORTUARY CHAMBERS.

A Door Between Worlds

The statue represents the god Serapis, whose cult was established in the 4th century BC in both Greece and Egypt. Serapis is of Greek origin, but obelisks and cubic stones, typical Egyptian monuments, also abound in Petra. For a long time, it was believed that Petra was the biblical town of Edom. Its strategic location made it a transit area for Indians and Africans. The Roman and Byzantine empires had a profound influence: Petra was their gateway to the East. Beginning in the 7th century, though, Nabataean culture began to merge with Islamic culture, and it ultimately disappeared.

SERAPIS
God of prosperity and concealed mysteries. In Egyptian iconography, Serapis has horns.

CORINTHIAN CAPITAL (Interpretation)
One of the most classic capitals of Greek architecture, along with the Ionic and Doric styles

WINGED LIONS (Interpretation)
These carvings were located in the temple of Atargatis, goddess of fertility in the Nabataean culture.

Carved in Stone

The construction over sandstone respects and takes advantage of the characteristics of the landscape. To create openings, builders used the cracks and fissures that already existed in the rock. The sandstone in Petra is composed of at least two original types of sediments of different colors. Some people believe they are from different geologic phases, but it is more likely that the original sand was made of different grains.

SANDSTONE
A sedimentary rock with medium-sized grains (less than 0.08 inch [2 mm]), with great toughness and hardness. Its mineralogical composition can vary. In the Jordanian desert, it forms cliffs.

Use of Rocks and Minerals

FOUND ALL OVER THE WORLD
Coal is found in almost all regions of the world, but today the only deposits of commercial importance are located in Europe, Asia, Australia, and the Americas.

IN DAILY LIFE 78-79
MOUNTAINS OF GOLD AND SILVER 80-81
AN OPEN-AIR MINE 82-83
BLINDED BY BRILLIANCE 84-85
BLACK AS COAL 86-87
BLACK GOLD 88-89
RADIOACTIVE MINERALS 90-91

Human beings have been extracting coal since ancient times, and mining generally takes place underground because most veins are hundreds of feet down. Human beings have to make incursions into the bowels of the Earth to extract its wealth. The materials extracted from the Earth are the basis of modern civilization, the raw material from which many products people use are made. Unfortunately, the Earth's reserves of coal, oil, and gas are being depleted. For this reason, other sources of energy to replace them are being sought. One of these alternative sources is nuclear energy. It requires uranium, an element found in certain rocks. ●

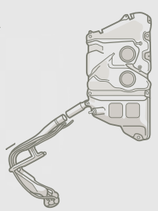
In Daily Life

It is impossible to conceive of modern life without the constant use of objects and materials made of rocks and minerals, metallic or nonmetallic. To illustrate this, it is enough simply to consider the elements that make up a car, trace them back to their origins, and consider the processes that shaped them. In some cases, the texture and characteristics of each material can be easily seen. Other materials, especially nonmetals such as coal and sulfur, are less noticeable, but they are a part of the production process as well. This process tends to emphasize and improve the physical, chemical, and electric characteristics of each material. ●

Hydrocarbons, the Source of Energy

The combustion of petroleum derivatives provides energy for propulsion. The combustion pathway begins with the storage of gas in the tank and ends with the expulsion of waste gases through the exhaust pipe. There a catalyst with thousands of cells filters the most toxic gases: carbon monoxide and nitrogen oxide.

EXHAUST PIPE



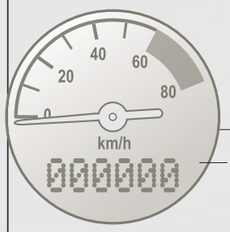
FUEL TANK

IRON
Strong and resistant

Electric Properties: Conductors, Insulators, and Semiconductors

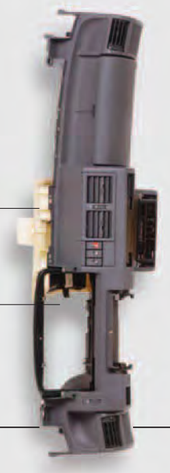
Metals, which tend to lose electrons, are the soul of electric cables and circuits. Nonmetals (and their polymeric derivatives) hinder the flow of electrons and are used as insulators. Other minerals, such as silicon, have intermediate properties: electronic components are manufactured by adding impurities to modify their properties.

CONTROL PANEL
In smaller contact areas, more expensive metals are used (gold is the best conductor). Chips and other electronic components contain silicon. Phosphorescent displays have strontium paint.



CIRCUITS
Gold, silver, palladium

DISPLAYS
Strontium



Metals

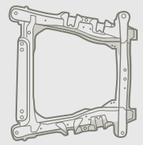
The body of a car is made of iron (present in both steel and magnetite), aluminum, and magnesium. Other metals are used to produce parts that are resistant to torsion (vanadium, cadmium), temperature (cobalt), and corrosion (nickel and zinc). Barium and platinum are used in very specific parts, and other metals are used in smaller amounts in lubricants, fluids, or paints.

BODYWORK
Aluminum, titanium, magnesium, and steel

ALUMINUM
Light and durable

20%
MORE ALUMINUM IS REQUIRED BY VOLUME FOR THE SAME WEIGHT OF STEEL.

SPRINGS
Cadmium



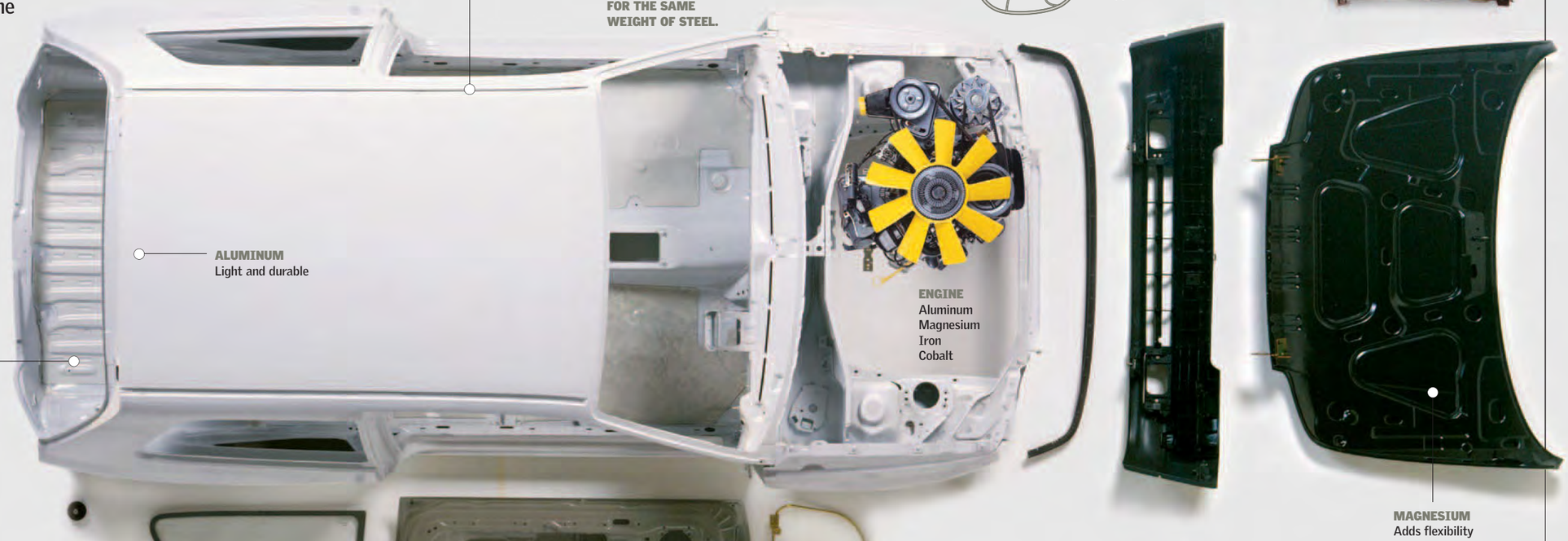
ENGINE BLOCK
It sustains the engine and is made of magnetite, an iron ore.

WIRING SYSTEM
Copper

SEAT

BACK
Glass fiber

SPRINGS
Steel



ENGINE
Aluminum
Magnesium
Iron
Cobalt

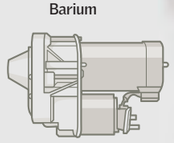
MAGNESIUM
Adds flexibility

0.07 pound (0.03 kg)
PER CUBIC INCH MAGNESIUM IS THE LIGHTEST METAL USED FOR INDUSTRIAL PURPOSES.

LOCKS
Covered with zinc

DISTRIBUTOR
Platinum

IGNITION COIL
Barium



HEADLIGHTS
Tungsten

MIRRORS
Glass and lead

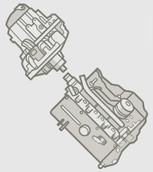
WINDOWS
Glass (silica)

Nonmetals

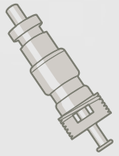
Silicon and its derivatives (silicone, silica, and silicates such as asbestos) are omnipresent materials in car manufacturing. They appear in crystallized form, such as quartz, and in noncrystallized—or glass—form. Other nonmetals aid in the strengthening of metals—for example, carbon in the production of steel and sulfur in the vulcanization of rubber.

WHEELS
Titanium is often used in alloys and in the car's finish.

STEERING WHEEL
Silicon coating



ENGINE JOINTS
Asbestos



SPARK PLUGS
Porcelain (kaolin)

TIRES
Vulcanized steel mesh

Mountains of Gold and Silver

From the decision to exploit an area where valuable minerals are suspected to exist to obtaining these minerals in major amounts, large-scale mining operations require complex work that lasts for years. For instance, the exploitation of Veladero, an open-air gold-and-silver mine located in the province of San Juan in the Argentinean Andes and exploited by the Canadian company Barrick Gold, required more than a decade of research and development before the first ingots were obtained in October 2005. To reach the deposits, roads and housing were built for the workers. The potential environmental impact of the mine was analyzed since explosives had to be used and toxic substances, such as cyanide, were needed for extracting and separating the rock from other metals. ●

VELADERO, ARGENTINA

Latitude 29° S

Longitude 70° W

Total land area	**1,158 square miles (3,000 sq km)**
Employed builders (peak)	**5,000**
Gold reserves (1st estimate)	**900 tons**
Estimated life span	**17 years**

HUGE OPEN-AIR MINE

Veladero—located in the Argentinean province of San Juan, as shown on the map—required 2,300 tons of metallic structures and consumes 2,520 tons of sodium cyanide per year for extracting gold.

13,120 feet (4,000 m)

ABOVE SEA LEVEL
The elevation of the mine

1. PROSPECTING
1 TO 3 YEARS
COST: $10 MILLION

Prospecting began in 1994. During this phase, the possible existence of a deposit covering a vast area was analyzed. It was necessary to draw maps, conduct studies, make satellite images, and undertake field trips to analyze superficial rocks.

3. BLUEPRINT OF THE MINE
2 TO 5 YEARS
COST: $547 MILLION

Once the reserves and costs were analyzed, it was necessary to open the mineral deposit and evaluate the environmental impact of the operation. The infrastructure was then built; it included paths, houses, and river diversions.

2. EXPLOITATION
2 TO 5 YEARS
COST: $90 MILLION

The first phases are involved with field prospecting. During this process, preliminary research is confirmed or revised. Once the existence of the deposit is confirmed, the next step is to establish its dimensions, reserves, yield, and extraction costs.

An Open-Air Mine

There are many types of mines. Some are located in the depths of the Earth, and some show their contents at its surface. Bingham Canyon, a copper mine located in Utah, is not only one of the most important open-air mines but also one of the largest excavations in the world. It is so large that it can be seen from space. It has been in operation since 1903, and it has been excavated in the form of terraces, like those used in agriculture. Its activity never stops, continuing even on weekends and holidays. The manner in which copper is extracted involves not only the use of machinery of extraordinary dimensions but also the use of a hydro-metallurgic chemical process called lixiviation, or leaching. Thanks to this process it is possible to obtain 99.9 percent of copper in its pure state from a copper concentration of 0.02 ounce per pound (0.56 gram per kg) of raw material.

BINGHAM CANYON UNITED STATES

Latitude 40° 32´ N
Longitude 112° 9´ W

Diameter of the pit	2.5 miles (4 km)
Depth of the pit	2,300 feet (700 m)
Opening year	1903
Closing year	2013
Number of employees	1,700

WATER BASIN
The phreatic layer, the closest aquifer to the surface below the water table, emerges at the bottom and forms a water basin with a peculiar color because of the copper salts in the deposit.

TERRACING OF THE SURFACE
The mine acquires a steplike shape because it is excavated in spiral terraces. The machines can move easily over the terraces, collecting the extracted material.

PATHS
The roads are well built, and they can withstand loads of up to 1,765 cubic feet (50 cu m) of rock on only one truck.

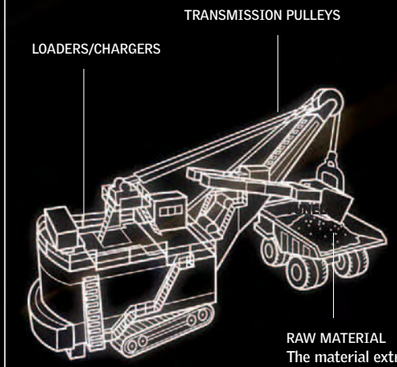
How the Metal Is Extracted

Thousands of pounds of explosives, trucks and shovels as large as a house, and massive grinding machines that can reduce hard rocks to dust are involved in the extraction process, and rock temperatures are raised to 4,500° F (2,500° C). In this way, copper is extracted from one of the largest open-air mines on the planet. The raw material excavated from the terraces in the mine contains oxidized copper minerals. This material is transported to grinders, which produce rock fragments 1.5 inches (4 cm) in diameter. These materials are placed in a pile that is treated with a solution of water and sulfuric acid. This process is called lixiviation, or leaching. Lixiviation is a hydro-metallurgic treatment that makes it possible to obtain copper present in the oxidized minerals. The treated material begins the process of sulfatation of copper contained in the oxidized minerals.

1 HOW MATERIAL IS OBTAINED

The process begins with rock perforation and blasting. The rock is removed from the pit and loaded by large shovels onto trucks. Then it is unloaded onto a mobile grinder. The ground rock is removed from the mine on conveyor belts and then sprayed with a solution of water and sulfuric acid.

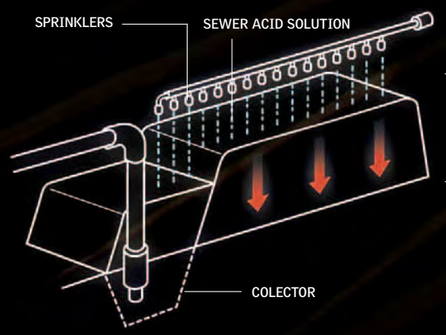
0.56 %
COPPER CONCENTRATION IN THE RAW MATERIAL



2 ARRANGEMENT OF THE STACK

When on the conveyor belts, the material is taken to a place where it will form a lixiviation pile or stack, and a trickle irrigation system is installed on top of this pile. Sprinklers cover the entire exposed area. The material will spend 45 days here.

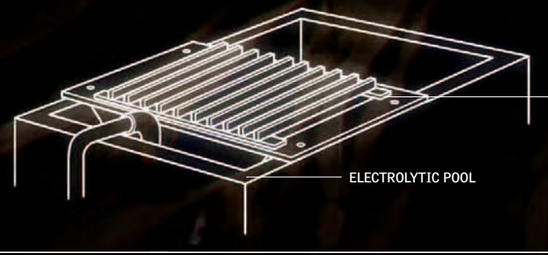
6 ounces/gallon (45 g/l)
OF COPPER IN THE SOLUTION AT THE END OF THE LIXIVIATION PROCESS



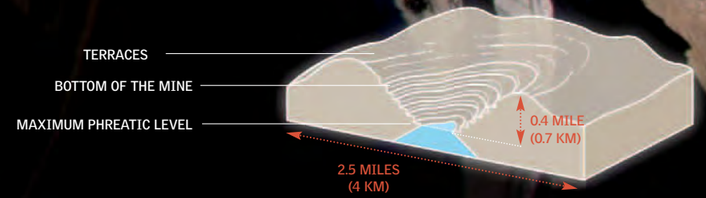
3 COPPER RECOVERY

The resulting copper solution is collected in conduits and then undergoes a process of electrolytic refining. During this process, electricity passes between two copper plates suspended in the solution; copper from the solution adheres to the sheets as it is separated through electrolysis.

99.9 %
COPPER IN A PURE STATE



LIXIVIATION
The hydro-metallurgic process that makes it possible to obtain copper from the oxidized minerals by applying a solution of sulfuric acid and water. Oxidized minerals are sensitive to attack by acid solutions.

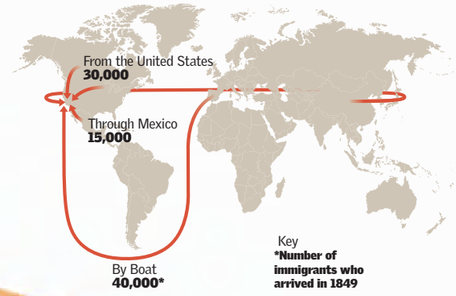


FORMATION OF THE MINE
Surface mines take the shape of large terraced pits, which grow ever deeper and wider. Viewed from above, an enormous spiraling hollow can be seen. This is a relatively inexpensive and simple method to extract high-purity materials.

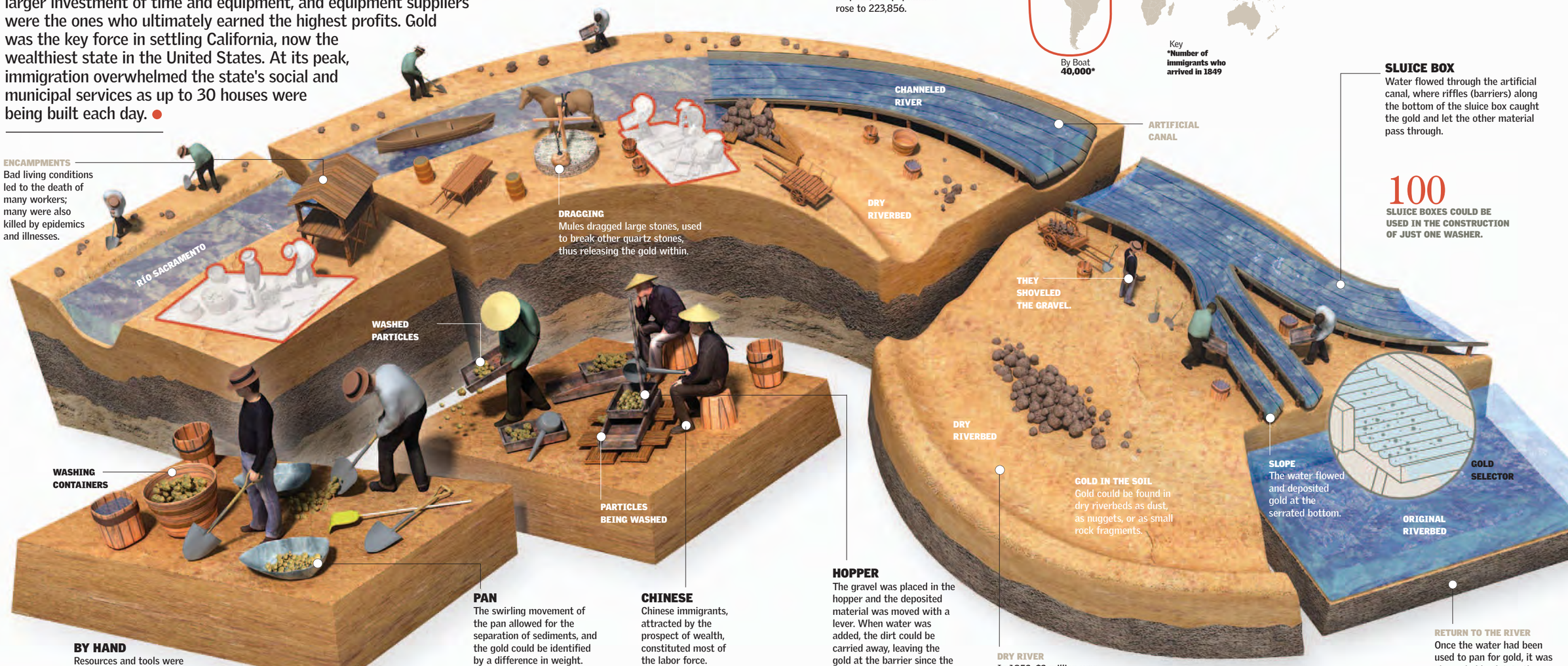
Blinded by Brilliance

The discovery of gold in the Sacramento River in California in the mid-19th century started one of the largest migrations of its time. Fortune hunters came from the Americas as well as from Asia, but few were able to achieve their goal of striking it rich. Each year, obtaining gold required a larger investment of time and equipment, and equipment suppliers were the ones who ultimately earned the highest profits. Gold was the key force in settling California, now the wealthiest state in the United States. At its peak, immigration overwhelmed the state's social and municipal services as up to 30 houses were being built each day.

FLOW OF IMMIGRANTS
In 1848, California had a population of 14,000. However, within four years and with the gold fever at its peak, the population rose to 223,856.



UNITED STATES
California
Sacramento River



1 1848
On the morning of January 24, while James Marshall was building a sawmill for his employer John Sutter, he discovered gold on the banks of the Sacramento River. This irrevocably changed the history of California.

$16
WAS THE PRICE OF A PLOT OF LAND; 18 MONTHS LATER, IT WAS PRICED AT $45,000.

2 1850
California became the 31st state of the Union. Slavery was abolished because of the large influx of immigrants and the fear that it would reduce workers' salaries. However, the Fugitive Slave Act was sanctioned by the state. According to this law, every fugitive slave that entered California had to be returned to his or her owner.

$500
MILLION IN GOLD WAS EXCHANGED DURING THE ENTIRE DECADE.

3 1852
When the surface gold was exhausted, more complex technology was required to extract it from the ground. Hydraulic mining, which used water jets, was a technique used for this purpose. Miners then became employees, enduring long workdays.

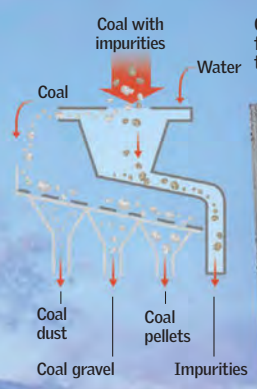
Black as Coal

In gallery or subterranean mines people must enter the bowels of the Earth to be able to extract the planet's mineral wealth. Some mines for extracting coal—the legendary driving force of the Industrial Revolution—are a clear example of this type of exploitation. Although these mines imply higher costs and labor risks, they have a lower environmental impact.

How Coal Is Extracted

6. DISTRIBUTION
Mine trains transport the coal from the mine to the point of consumption.

5. WASHING AND CLASSIFICATION
Coal that leaves the mine is mixed with mud and rocks. It must be washed and classified according to quality and size.



Coal is separated from other materials through decantation.

WASHING AND CLASSIFICATION BUILDING

EXTRACTION TOWER

VENTILATION
Without good ventilation, methane, an explosive gas, condenses in the galleries and creates the risk of explosions.

FRESH-AIR ENTRANCE

4. ELEVATION
From the main shaft, the coal is transferred to cargo elevators that transport it to the surface.

EXIT FOR CONTAMINATED AIR

SECONDARY SHAFT

GALLERY
Tunnel that is used for communication in the mine

MINER'S TRANSPORT

MOVEMENT IN THE GALLERIES
The miners travel on foot or by train to the coal vein.

3. TRANSPORTATION
The extracted coal is placed on the conveyor belts that take it to the main shaft, and from there it is taken to the surface.

MAIN SHAFT
16 TO 23 FEET (5 TO 7 M)

2. EXTRACTION
The method that is widely used is that of continuous mining. A machine extracts the coal mechanically.

Mobile Arm

Coal Vein

1. PERFORATION
A vertical shaft is perforated, allowing access to the coal vein.

1.8 tons
IS THE AMOUNT OF COAL THE PERFORATOR EXTRACTS IN AN HOUR.

CARGO ELEVATOR

TRANSPORTER BELT

5,000 feet (1.52 km)
THE SHAFTS CAN REACH THIS DEPTH.

60%
OF EXPLOITATION IS CARRIED OUT UNDERGROUND.

MAIN PRODUCERS
Year 2003. In millions of tons.

China	1,635
United States	1,070
India	503
Russia	294
South Africa	264

MAIN CONSUMERS
Year 2003. In millions of tons.

China	1,531
United States	1,094
India	430
Germany	273
South Africa	264

Black Gold

Because of its economic importance as a source of energy, petroleum, or oil, is called black gold. Searching for it requires large amounts of money and years of investigation and exploration, all with no guarantees. Once discovered, petroleum extraction entails the use of expensive machinery, which includes everything from oil pumps to refineries that convert oil into many derivative products. The oil trade is one of the most lucrative businesses worldwide, and a change in its price can affect national economies and put whole countries on guard. Petroleum is a nonrenewable source of energy.

How Petroleum Is Obtained

1. SEARCH
Indirect methods are used to detect the presence of hydrocarbons. However, the information obtained is not conclusive.

2. EXPLORATION
Once a deposit is detected, the soil is drilled to verify that there is petroleum with economic potential.

3. EXTRACTION
If the well is productive, the drilling towers are removed and extraction systems are installed.

4. TRANSPORTATION
Tankers transport crude oil to the refinery, where various products can be derived from it.

5. REFINING
The components of crude oil are separated, making use of the fact that each component boils at a different temperature. Refining is carried out by means of two main processes: fractional distillation and cracking.

NATURAL WAYS TO PUMP PETROLEUM

The driving force is the gas dissolved in a petroleum deposit.

The gas accumulated in the deposit pushes the petroleum outward.

Later as water is pumped in, it accumulates underneath the petroleum and pushes it upward.

By January 2005

25% of the world's merchant fleet was used to transport oil. There were 11,356 tankers.

FRACTIONAL DISTILLATION
Distillation Column
Crude Oil
Heat
Light Molecules
Molecules of Intermediate Weight
Hydrocarbon Molecules

CRACKING
Big molecules are broken down to create smaller ones.
Smaller Molecules

PRODUCTS OF DISTILLATION
Approximate Boiling Point
212º F (100º C) Gasoline
392º F (200º C) Kerosene
572º F (300º C) Diesel Oil
Fuel Oil
Residue
Gas
Fractioning Columns

Drilling Column or String
This pipe will be lowered into the ground.

Pipe for Delivering Drill Mud

Electric Motors

Pool for Recovering Drill Mud

SEISMIC TRUCK
These machines are located at different points within the research area.

GEOPHONE

Vibrating Sheet

Seismic Waves penetrate the layers of the Earth's crust and bounce back to the surface when the type of rock they pass through changes.

Bounced Waves
Geophones register these waves. A seismic section is generated based on the data obtained.

1 DRILLING
Powerful motors make the drilling string turn.

2 DRILL BIT
It advances through the rock formations that lie between the surface and the hydrocarbons below.

3 CAUTION
Once oil is detected, the drilling proceeds more slowly, and valves are closed to prevent the oil from gushing to the surface under high pressure.

EXPLORATORY WELL

Detail of the Drill Bit

Roller with Teeth

Solid Rock

DRILL MUD
flows down through the pipe and exits through the drill orifices.
As the mud rises, it carries rock that reveals which strata have been perforated.

PUMP ENGINE

Pumping systems
If oil does not flow naturally, it is extracted with a pumping system.

Oil Pump

CONTINENTAL CRUST

IMPROVEMENT IN OIL RECOVERY

1 INJECTION OF GAS OR WATER
is carried out under high pressure; the natural volume is increased.

2 RISING PETROLEUM
The injected material pushes up the petroleum and makes it rise faster.

LUTITE

GAS

PETROLEUM

WATER

SOLID ROCK

TANKER

Crude-Oil Deposit

Catalytic Cracking Plant

REFINERY

Machinery Room

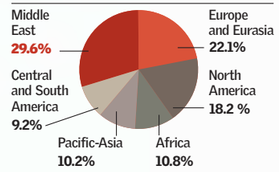
Cargo space divided into compartments

SEA

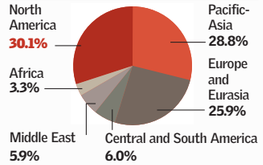
CONTINENTAL CRUST

77% OF ALL PETROLEUM PRODUCED IS EXTRACTED FROM UNDERGROUND DEPOSITS.

MAIN EXTRACTORS
Year: 2004



MAIN CONSUMERS
Year: 2004



North America and Pacific-Asia account for 90 percent of the increase in petroleum consumption over the last 10 years.

Radioactive Minerals

Uranium and plutonium were used for the first time—for military purposes—in the 1940s. Once World War II ended, nuclear reactors and their fuels began to be used as sources of energy. To process these minerals, nuclear plants are necessary. They must be built following many safety guidelines, since nuclear energy is considered to be very risky. Accidents like the one in Chernobyl and, more recently, in Tokaimura, Japan, are clear examples of what can happen when control of this form of energy is lost. These images show the structure and heart of a nuclear reactor, the way uranium is processed, and the peaceful uses of this type of energy.

Pressure Vessel

The nuclear reactor is inserted into a vessel formed by steel that is approximately 1.6 feet (0.5 m) thick. The fuel, which is encapsulated in zirconium alloy sheaths, is located inside the hollow space of the vessel. This design helps to meet one of the first goals in nuclear safety: to prevent radioactive products from leaking into the surrounding environment.

URANIUM HANDLING

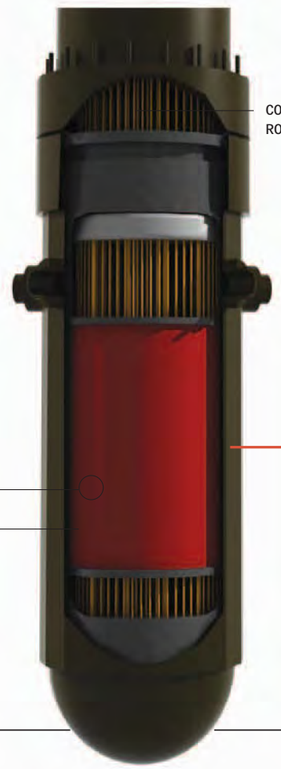
Uranium 235 is the only isotope that is found in a natural state, easily fissionable. For this reason, it is the main fuel used in nuclear power plants. Even though it is rare to find it in the Earth's crust, it can be found in enriching deposits in watercourse beds.

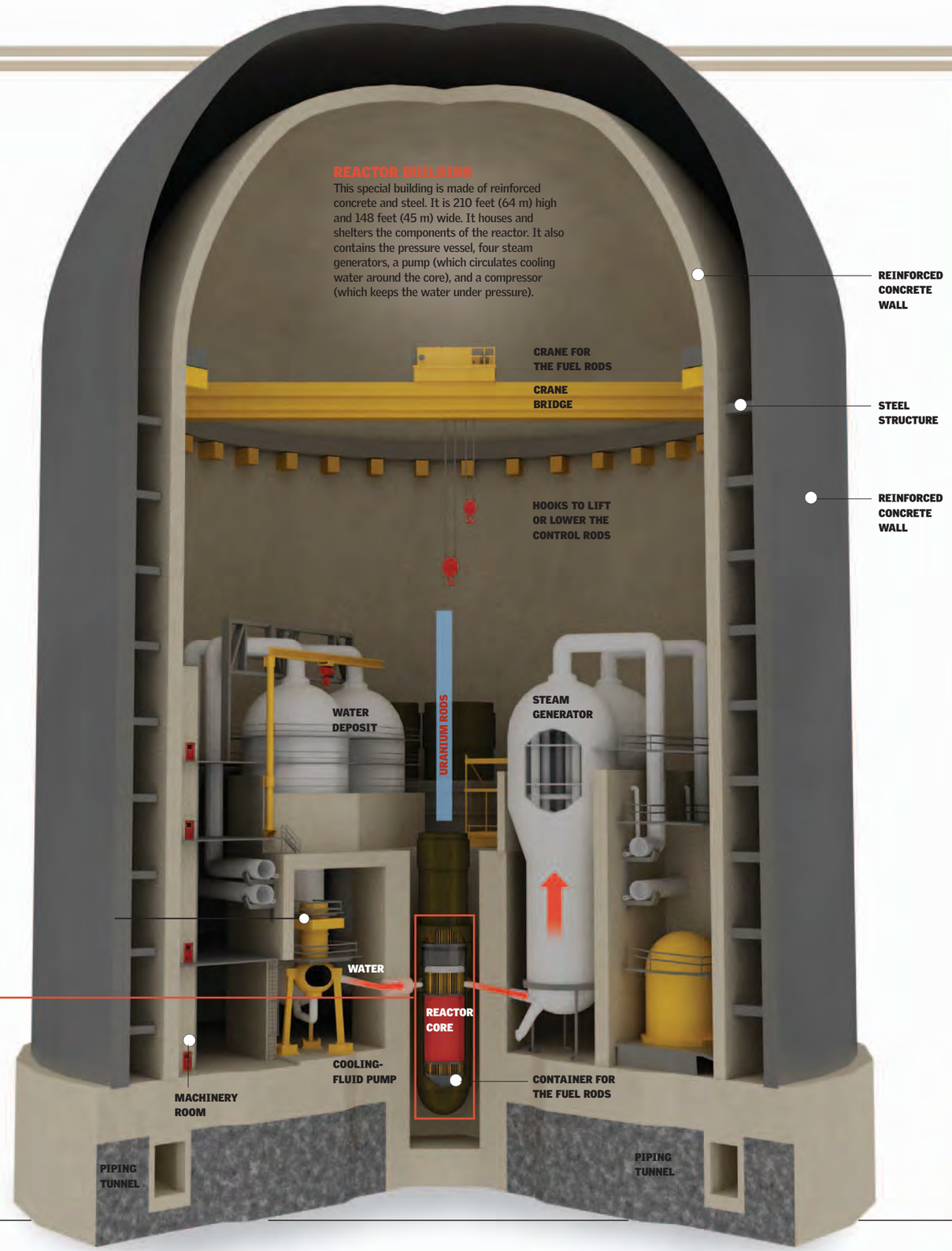
264
FUEL RODS IN EACH GROUP

THE NUCLEUS OF THE REACTOR

is in the lower part of the safety vessel, in which there are about 200 groups of fuel sheaths sized 0.4 inch (1 cm) in diameter and 13 feet (4 m) in height.

572° F
(300° C)
THE TEMPERATURE OF THE WATER PELLET





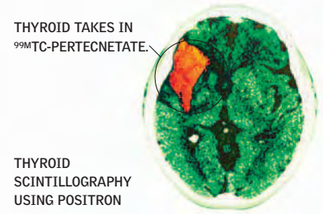
Carbon 14

is a method for dating organic fossil samples based on the exponential decay law of radioactive isotopes. After a living organism has been dead for 5,730 years, the amount of ^{14}C present in its body has decreased by half. Thus, when the amount of latent ^{14}C is measured in organic materials, it is possible to calculate the amount remaining in the material and, therefore, to calculate when the organism died.

50,000 years

USE OF URANIUM IN MEDICINE

The application of nuclear energy helps with the diagnosis and treatment of diseases such as cancer. It can detect alterations long before symptoms develop clinically, which allows for more effective early treatment.



SAFETY SUIT

To handle radioactive material, such as spent fuel bars, workers must wear a special suit because of the high levels of radiation.

Glossary

Alkalines

Minerals that have a high content of potassium, sodium, lithium, rubidium, and calcium.

Amorphous

Mineral with fractured surfaces instead of crystalline faces. Noncrystalline.

Anticline

A fold of sedimentary strata sloping upwards like an arch.

Asthenosphere

Layer inside the Earth, below the lithosphere. It is part of the upper mantle and is composed of easily deformable rock.

Atom

The smallest unit of matter.

Bacteria

Microscopic and unicellular life-form found in air, water, plants, animals, and on the Earth's crust.

Batholith

Great mass (larger than 60 square miles [100 sq km] of surface) of intrusive igneous rocks.

Bravais Lattices

Three-dimensional crystal systems, based on certain mathematical principles, that represent the 14 types of cell units.

Butte

Hill with a flat top and sloping sides, found in areas that have undergone intense erosion.

Canyon

Deep, narrow valley formed by fluvial erosion.

Carat

Unit of weight used in jewelry, variable in time and place, equivalent to 0.007 ounce (0.2 g).

Cave

Subterranean cavity formed through the chemical action of water on soluble, generally calcareous, ground.

Cementation

Process by which sediment both loses porosity and is lithified through the chemical precipitation of material in the spaces between the grains.

Cementation Zone

Place where lithification occurs. Water infiltrates the area, fills up the spaces between the grains of sediment, and transforms loose sediment into a solid mass.

Chasm, or Rift

Wide valley formed as a consequence of the extension of the crust at the boundaries of diverging tectonic plates.

Chemical Compound

Substance formed by more than one element.

Chemical Element

Substance that contains only one type of atom.

Clay

Fine-grained sediments formed by the chemical decomposition of some rocks. It is malleable when wet and hardens as it dries.

Coal

Combustible black rock of organic origin. It is produced through the decomposition of plant materials that accumulate in swamps or shallow marine waters.

Concretion

Hard mass of mineral material that usually holds a fossil inside.

Contact Metamorphism

Large-scale transformation of a rock into another type of rock. This happens mostly as a consequence of a sudden temperature increase.

Convection Currents

Moving pathways of material that occur inside the mantle as a consequence of the transfer of heat coming from the Earth's core. The hottest zones of the mantle rise, and the coldest ones sink. These movements are probably responsible for the movement of tectonic plates.

Crack

Fissure or cavity in the rock that results from tension. It can be completely or partially filled with minerals.

Crust

External layer of the Earth. There are two types of crust: continental crust forms large terrestrial masses, and oceanic crust forms the bottoms of the oceans.

Crystal

Organized, regular, and periodically repeated arrangement of atoms.

Crystalline System

It includes all crystals that can be related to the same set of symmetric elements.

Density

Amount of mass of a mineral per unit of volume.

Deposit

A natural accumulation of a rock or mineral. If it is located at the site where it formed, the deposit is called primary. Otherwise, it is called secondary.

Diatomite

Light, porous rock. It has a light color, and it is consolidated. Composed exclusively (or almost) of diatoms.

Dolostone

Carbonated sedimentary rock that contains at least 50 percent or more carbonate, of which at least half appears as dolomite.

Earthquake

The sudden and violent release of energy and vibrations in the Earth that generally occurs along the edges of tectonic plates.

Elasticity

Tendency of a mineral to recover its shape after being subjected to flexion or torsion.

Era

Division of time in the Earth's history. Geologists divide eras into periods.

Erosion

Removal and transport of sediment through the action of water, ice, and wind.

Evaporation

Process through which a liquid becomes gas without boiling.

Exfoliation

The tendency for certain minerals to fracture along regular planes within their crystalline structure.

Fault

Fracture involving the shifting of one rock mass with respect to another.

Flexibility

Ability of minerals to bend without fracturing.

Fluorescence

Property of some minerals that enables them to emit a certain level of light when exposed to ultraviolet rays. The fluorescent properties present in a metal can make it look as if it were truly fluorescent.

Fold

Bending and deformation of rock strata due to the compression caused by the movements of tectonic plates.

Fossil

Any trace of an old life-form. It can be the petrified remains of an organism or an impression of an organism left in rock.

Fossil Fuel

Fuel formed from the partially decomposed remains of deceased organisms. These mixtures of organic compounds are extracted from the subsoil with the goal of producing energy through combustion. They are coal, oil, and natural gas.

Fracture

Break of a mineral along an irregular surface. It can be conchoidal, hooked, smooth, or earthy.

Gem

Mineral or other natural material that is valued for its beauty and rarity. It can be polished and cut to produce jewels.

Geode

Spherical, rocky cavity covered with well-formed crystals.

Geology

Study of the Earth, its shape, and its composition. Rocks, minerals, and fossils offer information that helps us reconstruct the history of the planet.

Glacier

A large mass of ice formed through the accumulation of recrystallized and compacted snow occurring either on a mountain or over a large area on a landmass. Ice moves slowly and both excavates rock and carries debris.

Granite

Intrusive igneous rock composed mainly of quartz and feldspar. It can be polished and used in decoration.

Habit

External aspect of a crystal that reflects its predominant shape.

Hardness

Resistance offered by a mineral to scratching and abrasion. One mineral is said to be harder than another if the former can scratch the latter.

Hot Spot

Place within a tectonic plate where active volcanoes form.

Hydrothermal

Process involving the physical and chemical transformations suffered by rocks or minerals through the action of hot fluids (water and gases) associated with a magma body.

Igneous Rocks

Rocks formed directly from the cooling of magma. If they solidify inside the crust, they are said to be plutonic (or intrusive); if they solidify on the surface, they are said to be volcanic (or extrusive).

Impermeable Rock

Rock through which liquids cannot be filtered.

Intrusion

A large mass of rock that forms in empty spaces underground when magma infiltrates strata, cools, and solidifies.

Jade

White or green metamorphic rock formed by a compact and tenacious filter of very fine needles of tremolite. It is a rare rock used in art objects.

Karst Cycle

Formation cycle of caves that lasts a total of about one million years.

Kimberlite

Type of rock usually associated with diamonds and other minerals coming from the depths of the Earth.

Lava

Magma expelled on the surface of the Earth.

Limestone

Rock containing at least 50% calcite. It can also have dolomite, aragonite, and siderite.

Lithosphere

Exterior, rigid layer of the Earth formed by the crust and upper mantle.

Lode

Sub-superficial rock intrusion of tabular-shaped rock.

Luster

Level of light reflection on the surface of a crystal.

Magma

Hot, rocky material from the crust and upper mantle in liquid state that forms crystals as it cools. When magma is expelled at the Earth's surface, it is called lava.

Magmatic Rock

Rock that forms when magma cools off and solidifies. Magmatic intrusive rocks solidify underground, while the extrusive ones solidify on the surface.

Magnetism

Property of some minerals that allows them to be attracted by a magnet and to change the direction of a compass needle.

Malleability

Mechanical property of a mineral that makes it possible for the mineral to be molded and formed into a sheet through repeated blows without breaking.

Mantle

The layer between the crust and external core. It includes the upper mantle and lower mantle.

Marble

Metamorphosed limestone rock composed of compacted calcite and dolomite. It can be polished.

Massive

One of the possible habits of a consistent mineral that refers to the tendency for certain crystals to intertwine and form a solid mass rather than independent crystals.

Metal

Any element that shines, conducts electricity, and is malleable.

Metamorphic Rock

Type of rock resulting from the application of high pressure and temperature on igneous and sedimentary rocks.

Mineral

Inorganic solid of natural origin that has an organized atomic structure.

Mohs Scale

A tool designed to test the hardness of a given mineral by comparing it to 10 known minerals, from the softest to the hardest. Each mineral can be scratched by those following it.

Molecule

Chemical compound formed when one or several types of atoms are joined together.

Native Element

An element that occurs in nature that is not combined with other elements. Sulfur and gold are examples of native elements.

Oceanic Trench

Narrow and deep submarine depression formed when the oceanic crust of one tectonic plate moves beneath another.

Ornamental Stone

It is not a precious stone, but it can be used in jewelry or for other ornamental purposes.

Outcrop

Part of a rock formation devoid of vegetation or soil that stands out from the Earth's surface.

Oxidation Zone

Deposit of minerals with oxidizing properties, formed through the effect of meteorization or weathering.

Petrifaction

Cell-by-cell replacement of organic matter, such as bones or wood, with minerals of the surrounding solutions.

Piezoelectric

Property that some minerals have to produce a difference in potential when subjected to compression, traction, or torsion.

Placer

Mineral concentrations as deposits of placer during time lapses that vary from a few decades up to millions of years.

Pyroelectric

Property that some nonconductor minerals have to create difference in power transmissions from differences in temperature.

Quartzite

Metamorphic rock formed by the consolidation of quartz sandstone. It is extremely hard. Quartzite can also be a sedimentary rock, which is sandstone with a very high content of quartz; it is very hard and it has light color.

Regional Metamorphism

Metamorphism occurring in rock over large areas.

Rock

Natural aggregate of one or more minerals (sometimes including noncrystalline substances) that constitute an independent geologic unit.

Sedimentary Rock

Rock that forms through accumulation of sediments that, when subjected to physical and chemical processes, result in a compacted and consolidated material. Sediment can form on river banks, at the bottom of precipices, in valleys, lakes, and seas. Sedimentary rock accumulates in successive layers, or strata.

Sediments

Rock fragments or remains of plants or animals deposited at the bottom of rivers, lakes, or oceans by water, wind, or ice.

Seismic Waves

Elastic waves that travel through the Earth after an earthquake. They can also be produced artificially through explosions.

Silicates

They make up about 95 percent of the Earth's crust. Their tetrahedral structure, with one silicon and four oxygen ions, creates different types of configurations through the union of the ions. According to their composition, members of this mineral group are differentiated into light and dark.

Slate

Bluish black, fine-grained metamorphic rock. It can be easily divided into sheets.

Solution

Mixture of two or more chemical substances. It can be liquid, solid, or gaseous.

Stalactite

Internal structure of a cave. It is conical and hangs from the cave ceiling.

Stalagmite

Internal structure of a cave. It is conical and rises from the cave floor.

Streak

Characteristic color of the fine dust obtained from a mineral by rubbing it over an unglazed porcelain plate.

Streak Test

A test that involves rubbing a mineral against an unglazed white porcelain sheet to obtain dust. The color of the dust left on the tile can help identify the mineral.

Symmetry Axes

Symmetry element that enables the repetition of crystalline faces to form different shapes.

Syncline

Concave fold of sedimentary rock strata. The younger rocks are located at the center of the concave.

Talus Slope

Accumulation of fragments resulting from the mechanical weathering of rocks. The sediment deposit forms more or less in situ as the result of the transport of materials through gravity over a small distance.

Tectonic Elevation

Rising of rocks as a consequence of the movements of tectonic plates.

Tectonic Plates

Rigid fragments of the lithosphere that move on the asthenosphere.

Tenacity

The level of toughness that a mineral offers to fracture, deformation, crushing, bending, or pulverization.

Transparent

It is said that a mineral is clear when light goes through it without weakening. When only some light passes through, the mineral is called translucent. If no light passes through, it is called opaque.

Vein

Fracture that cuts through rocks and is filled by some mineral.

Volcanic Outcropping

Isolated pile of hard magmatic rocks that remain after the disappearance of the rest of the volcano due to erosion.

Weathering

The breaking down of a material by sustained physical or chemical processes.

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ROCKS AND MINERALS

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VOLCANOES AND EARTHQUAKES

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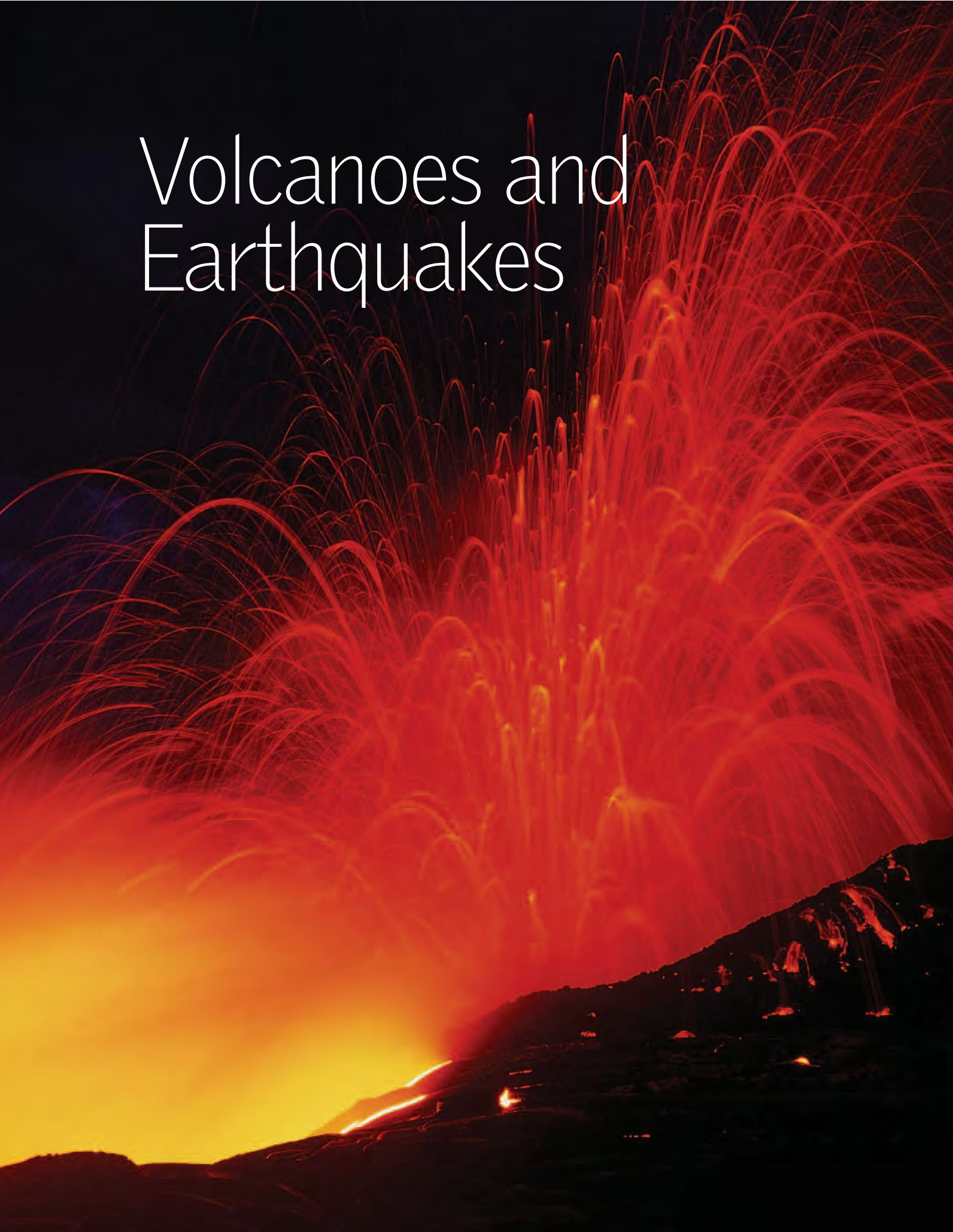

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Kashmir, 2005
Farmer Farid Hussain, 50, grasps the hand of his wife, Akthar Fatma, after the earthquake that rocked the Himalayas on the Indian subcontinent. Eighty thousand people were killed, and thousands of families were left homeless.

The Power of Nature

Some photos speak for themselves. Some gestures communicate more than words ever could, like these clasped hands, which seek comfort in the face of fear of the unknown. The picture was taken Oct. 8, 2005, when aftershocks were still being felt from the strongest earthquake ever to strike Kashmir, in northern India. Those clasped hands symbolize terror and panic; they speak of fragility and helplessness, of endurance in the face of chaos. Unlike storms and volcanic eruptions, earthquakes are unpredictable, unleashed within seconds, and without warning. They spread destruction and death, forcing millions to flee from their homes. The day after the catastrophe revealed a terrifying scene: debris everywhere, a number of people injured and dead, others wandering desperately, children crying, and over three million survivors seeking help after losing everything. Throughout history Earth has been shaken by earthquakes of greater or lesser violence. These earthquakes have caused great harm. One of the most famous is the earthquake that rocked San Francisco in 1906. Registering 8.3 on the Richter scale, the temblor left nearly three thousand dead and was felt as far away as Oregon to the north, and Los Angeles in southern California.

The purpose of this book is to help you better understand the causes of fractures and the magnitude and violence of the forces deep within the earth. The full-color, illustrated book you hold in your hands contains shocking scenes of cities convulsed by earthquakes and volcanoes, natural phenomena that, in mere seconds, unleash rivers of fire, destroy buildings, highways and bridges, and gas and water lines and leave entire cities without electricity or phone service. If fires cannot be put out quickly, the results are even more devastating. Earthquakes near coastlands can cause tsunamis, waves that spread across the ocean with the speed of an airplane. A tsunami that reaches a coast can be more destructive than the earthquake itself. On Dec. 26, 2004, the world witnessed one of the most impressive natural disasters ever. An undersea quake with a magnitude of 9 on the Richter scale shook the eastern Indian Ocean, causing tsunamis that reached the coastal areas of eight Asian nations, causing about 230,000 deaths. The earthquake was the fifth strongest since the invention of the seismograph. Satellite images show the region before and after the catastrophe.

Throughout history, nearly all ancient peoples and large societies have thought of volcanoes as dwelling places of gods or other supernatural beings to explain the mountains' fury. Hawaiian mythology, for instance, spoke of Pele, the goddess of volcanoes, who threw out fire to cleanse the earth and fertilize the soil. She was believed to be a creative force. Nowadays, specialists try to find out when a volcano might start to erupt, because within hours after an eruption begins, lava flows can change a lush landscape into a barren wilderness. Not only does hot lava destroy everything in its path, but gas and ash expelled in the explosion also replace oxygen in the air, poisoning people, animals, and plants. Amazingly, life reemerges once again from such scenes of destruction. After a time, lava and ash break down, making the soil unusually fertile. For this reason many farmers and others continue to live near these "smoking mountains," in spite of the latent danger. Perhaps by living so close to the danger zone, they have learned that no one can control the forces of nature, and the only thing left to do is to simply live.

Continuous Movement

PAHOEHOE LAVA
A type of Hawaiian lava that flows down the slopes of Mt. Kilauea to the sea.

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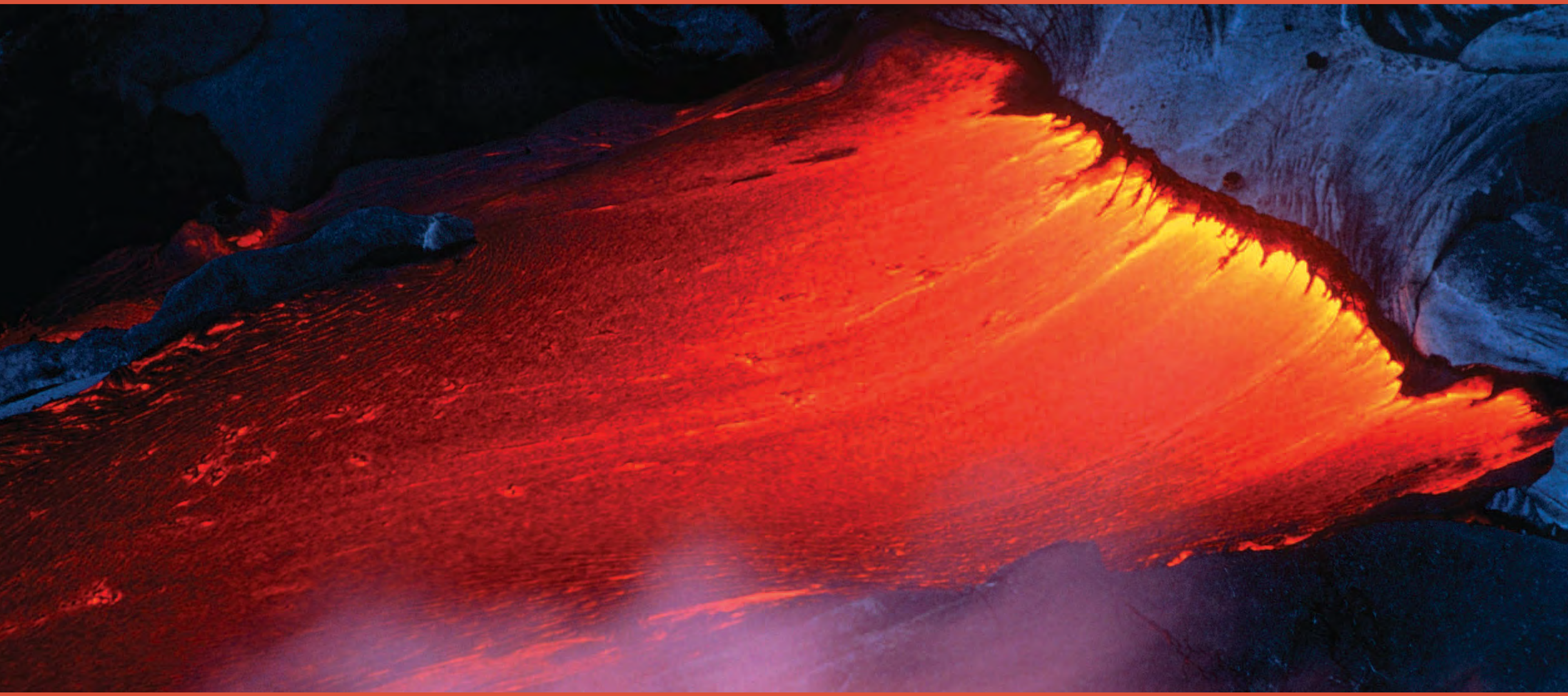


In the volatile landscape of Volcano National Park in Hawaii, the beginning and end of life seem to go hand in hand. Outpourings of lava often reach the sea. When the molten rock enters the water, the lava quickly cools and hardens into rock that becomes part of the coastline. By this process, volcanic islands grow constantly, and nothing stays the same from one moment to another. One day rivers of lava blaze down the volcano's slopes, and the next day there are new, silver-colored rocks. The ongoing investigation of lava samples under the microscope helps volcanologists discover the rock's mineral composition and offers clues about how the volcano may behave.●

Scorching Flow

Most of the Earth's interior is in a liquid and incandescent state at extremely high temperatures. This vast mass of molten rock contains dissolved crystals and water vapor, among other gases, and it is known as magma. When part of the magma rises toward the Earth's surface, mainly through volcanic activity, it is called lava. As soon as it reaches the surface of the Earth or the ocean floor, the lava starts to cool and solidify into different types of rock, according to its original chemical composition. This is the basic process that formed the surface of our planet, and it is the reason the Earth's surface is in constant flux. Scientists study lava to understand our planet better.

Streams of Fire

Lava is at the heart of every volcanic eruption. The characteristics of lava vary, depending on the gases it contains and its chemical composition. Lava from an eruption is loaded with water vapor and gases such as carbon dioxide, hydrogen, carbon monoxide, and sulfur dioxide. As these gases are expelled, they burst into the atmosphere, where they create a turbulent cloud that sometimes discharges heavy rains. Fragments of lava expelled and scattered by the volcano are classified as bombs, cinders, and ash. Some large fragments fall back into the crater. The speed at which lava travels depends to a great extent on the steepness of the sides of the volcano. Some lava flows can reach 90 miles (145 km) in length and attain speeds of up to 30 miles per hour (50 km/hr).

INTENSE HEAT
Lava can reach temperatures above 2,200º F (1,200º C). The hotter the lava, the more fluid it is. When lava is released in great quantities, it forms rivers of fire. The lava's advance is slowed down as the lava cools and hardens.

Rock Cycle

Once it cools, lava forms igneous rock. This rock, subjected to weathering and natural processes such as metamorphism and sedimentation, will form other types of rocks that, when they sink back into the Earth's interior, again become molten rock. This process takes millions of years and is known as the rock cycle.

SEDIMENTARY ROCK
Rock formed by eroded and compacted materials.

METAMORPHIC ROCKS
Their original structure is changed by heat and pressure.

TURNS BACK INTO LAVA

TURNS BACK INTO LAVA

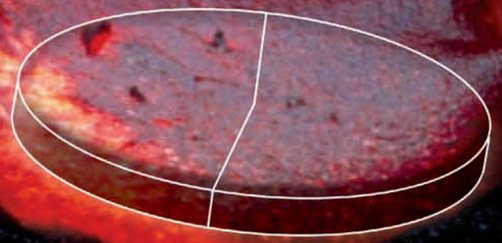
2. IGNEOUS ROCK
Rock formed when lava solidifies. Basalt and granite are good examples of igneous rocks.

1. LAVA
The state in which magma flows to the Earth's outer crust, either reaching the surface or getting trapped within the crust.

SOLID LAVA
Lava solidifies at temperatures below 1,700º F (900º C). The most viscous type of lava forms a rough landscape, littered with sharp rocks; more fluid lava, however, tends to form flatter and smoother rocks.

Mineral Composition

Lava contains a high level of silicates, light rocky minerals that make up 95 percent of the Earth's crust. The second most abundant substance in lava is water vapor. Silicates determine lava's viscosity, that is, its capacity to flow. Variations in viscosity have resulted in one of the most commonly used classification systems of lava: basaltic, andesitic, and rhyolitic, in order from least to greatest silicate content. Basaltic lava forms long rivers, such as those that occur in typical Hawaiian volcanic eruptions, whereas rhyolitic lava tends to erupt explosively because of its poor fluidity. Andesitic lava, named after the Andes mountains, where it is commonly found, is an intermediate type of lava of medium viscosity.

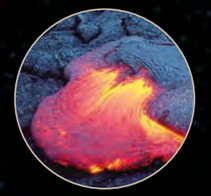


52% **Silicates**

48% **Other Content**

1,800º F (1,000º C)
is the average temperature of liquid lava.

TYPES OF LAVA
Basaltic lava is found mainly in islands and in mid-ocean ridges; it is so fluid that it tends to spread as it flows. Andesitic lava forms layers that can be up to 130 feet (40 m) thick and that flow very slowly, whereas rhyolitic lava is so viscous that it forms solid fragments before reaching the surface.



Andesitic Lava

Silicates	63%
Other Content	37%

Rhyolitic Lava

Silicates	68%
Other Content	32%

The Long History of the Earth

The nebular hypothesis developed by astronomers suggests that the Earth was formed in the same way and at the same time as the rest of the planets and the Sun. It all began with an immense cloud of helium and hydrogen and a small portion of heavier materials 4.6 billion years ago. Earth emerged from one of these "small" revolving clouds, where the particles constantly collided with one another, producing very high temperatures. Later, a series of processes took place that gave the planet its present shape.

From Chaos to Today's Earth

Earth was formed 4.6 billion years ago. In the beginning it was a body of incandescent rock in the solar system. The first clear signs of life appeared in the oceans 3.6 billion years ago, and since then life has expanded and diversified. The changes have been unceasing, and, according to experts, there will be many more changes in the future.

4.6 BILLION YEARS AGO

FORMATION

The accumulation of matter into solid bodies, a process called accretion, ended, and the Earth stopped increasing in volume.

4.5 BILLION YEARS AGO

COOLING

The first crust formed as it was exposed to space and cooled. Earth's layers became differentiated by their density.

4 BILLION YEARS AGO

METEORITE COLLISION

Meteorite collisions, at a rate 150 times as great as that of today, evaporated the primitive ocean and resulted in the rise of all known forms of life.

3.8 BILLION YEARS AGO

ARCHEAN EON

STABILIZATION

The processes that formed the atmosphere, the oceans, and protolife intensified. At the same time, the crust stabilized, and the first plates of Earth's crust appeared. Because of their weight, they sank into Earth's mantle, making way for new plates, a process that continues today.

The oldest rocks appeared.

When the first crust cooled, intense volcanic activity freed gases from the interior of the planet, and those gases formed the atmosphere and the oceans.

THE AGE OF THE SUPER VOLCANOES

Indications of komatite, a type of igneous rock that no longer exists.

2.3 BILLION YEARS AGO

"SNOWBALL" EARTH

Hypothesis of a first, great glaciation.

2.2 BILLION YEARS AGO

WARMING

Earth warmed again, and the glaciers retreated, giving way to the oceans, in which new organisms would be born. The ozone layer began to form.

1.8 BILLION YEARS AGO

PROTEROZOIC EON

CONTINENTS

The first continents, made of light rocks, appeared. In Laurentia (now North America) and in the Baltic, there are large rocky areas that date back to that time.

1.0 BILLION YEARS AGO

SUPERCONTINENTS

Rodinia, the first supercontinent, formed, but it completely disappeared about 650 million years ago.

540 MILLION YEARS AGO

PALEOZOIC ERA

FRAGMENTATION

The great landmass formed that would later fragment to provide the origin of the continents we have today. The oceans reached their greatest rate of expansion.

60 MILLION YEARS AGO

FOLDING IN THE TERTIARY PERIOD

The folding began that would produce the highest mountains that we now have (the Alps, the Andes, and the Himalayas) and that continues to generate earthquakes even today.

Stacked Layers

Every 110 feet (33 m) below the Earth's surface, the temperature increases by 1.8 degrees Fahrenheit (1 degree Celsius). To reach the Earth's center—which, in spite of temperatures above 12,000° F (6,700° C), is assumed to be solid because of the enormous pressure exerted on it—a person would have to burrow through four well-defined layers. The gases that cover the Earth's surface are also divided into layers with different compositions. Forces act on the Earth's crust from above and below to sculpt and permanently alter it.

Earth's crust

Earth's crust is its solid outer layer, with a thickness of 3 to 9 miles (4 to 15 km) under the oceans and up to 44 miles (70 km) under mountain ranges. Volcanoes on land and volcanic activity in the mid-ocean ridges generate new rock, which becomes part of the crust. The rocks at the bottom of the crust tend to melt back into the rocky mantle.

KEY Sedimentary Rock · Igneous Rock · Metamorphic Rock

THE SOLID EXTERIOR
The crust is made up of igneous, sedimentary, and metamorphic rock, of various typical compositions, according to the terrain.

MOUNTAIN RANGES
Made up of the three types of rock in about equal parts.

THE CONTINENTAL SHELF
In the area where the oceanic crust comes in contact with a continent, igneous rock is transformed into metamorphic rock by heat and pressure.

THE MID-OCEAN RIDGES
The ocean floor is regenerated with new basaltic rock formed by magma that solidifies in the rifts that run along mid-ocean ridges.

OCEANIC ISLANDS
Some sedimentary rocks are added to the predominantly igneous rock composition.

GRANITIC BATHOLITHS
Plutons can solidify underground as masses of granite.

PLUTONS
Masses of rising magma trapped within the Earth's crust. Their name is derived from Pluto, the Roman god of the underworld.

INTERNAL ROCK
The inside of a mountain range consists of igneous rock (mostly granite) and metamorphic rock.

COASTAL ROCK
Lithified layers of sediments, usually clay and pebbles, that come from the erosion of high mountains.

CRUST
3-44 miles
(5-70 km)

The Gaseous Envelope

The air and most of the weather events that affect our lives occur only in the lower layer of the Earth's atmosphere. This relatively thin layer, called the troposphere, is up to 10 miles (16 km) thick at the equator but only 4 miles (7 km) thick at the poles. Each layer of the atmosphere has a distinct composition.

Less than
6 miles
(10 km)
TROPOSPHERE
Contains 75 percent of the gas and almost all of the water vapor in the atmosphere.

Less than
31 miles
(50 km)
STRATOSPHERE
Very dry; water vapor freezes and falls out of this layer, which contains the ozone layer.

Less than
62 miles
(100 km)
MESOSPHERE
The temperature is -130º F (-90° C), but it increases gradually above this layer.

Less than
310 miles
(500 km)
THERMOSPHERE
Very low density. Below 155 miles (250 km) it is made up mostly of nitrogen; above that level it is mostly oxygen.

Greater than
310 miles
(500 km)
EXOSPHERE
No fixed outer limit. It contains lighter gases such as hydrogen and helium, mostly ionized.

UPPER MANTLE
370 miles
(600 km)

LITHOSPHERE
Includes the solid outer part of the upper mantle, as well as the crust.
93 miles
(150 km)

LOWER MANTLE
1,430 miles
(2,300 km)
Composition similar to that of the crust, but in a liquid state and under great pressure, between 1,830° and 8,130° F (1,000° and 4,500° C).

ASTHENOSPHERE
Underneath is the asthenosphere, made up of partially molten rock.
280 miles
(450 km)

OUTER CORE
1,410 miles
(2,270 km)
Composed mainly of molten iron and nickel among other metals at temperatures above 8,500º F (4,700° C).

INNER CORE
756 miles
(1,216 km)
The inner core behaves as a solid because it is under enormous pressure.

The Journey of the Plates

When geophysicist Alfred Wegener suggested in 1910 that the continents were moving, the idea seemed fantastic. There was no way to explain the idea. Only a half-century later, plate tectonic theory was able to offer an explanation of the phenomenon. Volcanic activity on the ocean floor, convection currents, and the melting of rock in the mantle power the continental drift that is still molding the planet's surface today.

Continental Drift

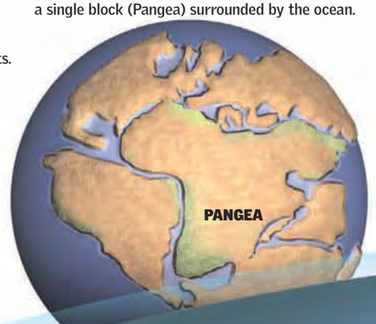
The first ideas on continental drift proposed that the continents floated on the ocean. That idea proved inaccurate. The seven tectonic plates contain portions of ocean beds and continents. They drift atop the molten mantle like sections of a giant shell. Depending on the direction in which they move, their boundaries can converge (when they tend to come together), diverge (when they tend to separate), or slide horizontally past each other (along a transform fault).

The Hidden Motor

Convection currents of molten rock propel the crust. Rising magma forms new sections of crust at divergent boundaries. At convergent boundaries, the crust melts into the mantle. Thus, the tectonic plates act like a conveyor belt on which the continents travel.

250 MILLION YEARS AGO

The landmass today's continents come from was a single block (Pangea) surrounded by the ocean.



...180 MILLION YEARS AGO

The North American Plate has separated, as has the Antarctic Plate. The supercontinent Gondwana (South America and Africa) has started to divide and form the South Atlantic. India is separating from Africa.

...100 MILLION YEARS AGO

The Atlantic Ocean has formed. India is headed toward Asia, and when the two masses collide, the Himalayas will rise. Australia is separating from Antarctica.

... 60 MILLION YEARS AGO

The continents are near their current location. India is beginning to collide with Asia. The Mediterranean is opening, and the folding is already taking place that will give rise to the highest mountain ranges of today.

250 MILLION YEARS

The number of years it will take for the continents to drift together again.

2 inches (5 cm)

Typical distance the plates travel in a year.

CONVERGENT BOUNDARY

When two plates collide, one sinks below the other, forming a subduction zone. This causes folding in the crust and volcanic activity.

DIVERGENT BOUNDARY

When two plates separate, a rift is formed between them. Magma exerts great pressure, and it renews the ocean floor as it solidifies. The Atlantic Ocean was formed in this way.

CONVECTION CURRENTS

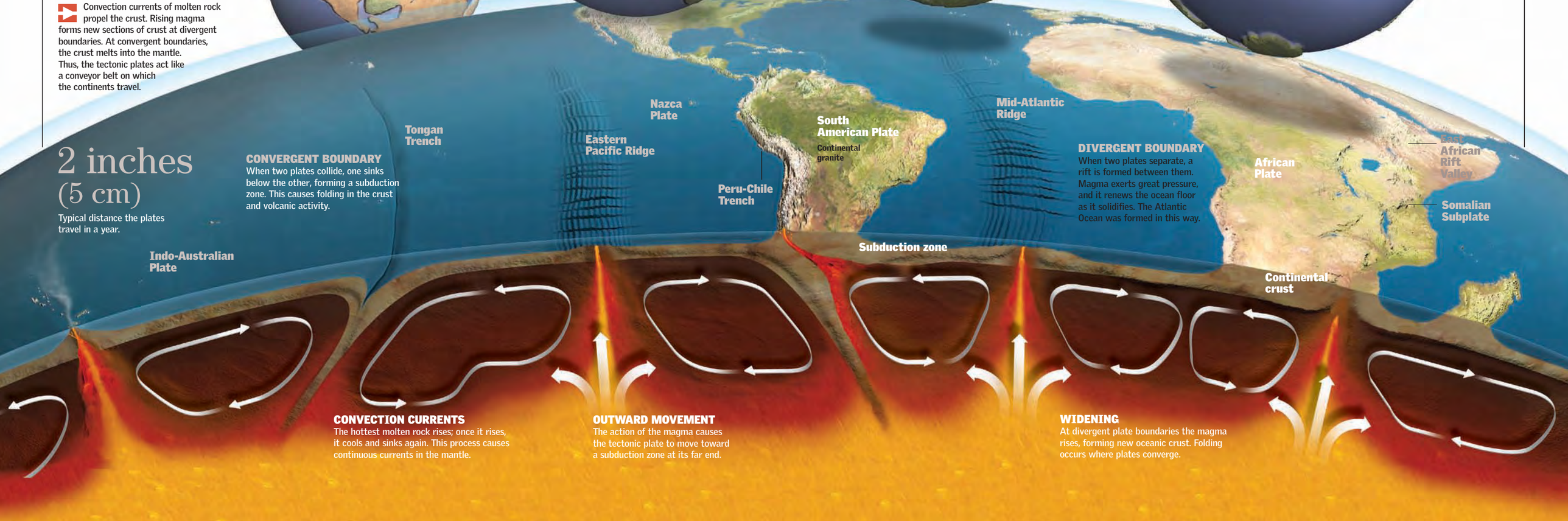
The hottest molten rock rises; once it rises, it cools and sinks again. This process causes continuous currents in the mantle.

OUTWARD MOVEMENT

The action of the magma causes the tectonic plate to move toward a subduction zone at its far end.

WIDENING

At divergent plate boundaries the magma rises, forming new oceanic crust. Folding occurs where plates converge.



Cracks in the Ocean Floor

The concept that the ocean floor is spreading was studied for many years: new crust constantly forms at the bottom of the ocean. The ocean floor has deep trenches, plains, and mountain ranges. The mountain ranges are higher than those found on the continents but with different characteristics. The spines of these great mountain ranges, called mid-ocean ridges, exhibit incredible volcanic activity in rift zones. The rift zones are fissures in relatively narrow regions of the crust, along which the crust splits and spreads. One hundred eighty million years ago, the paleocontinent Gondwana broke apart, forming a rift from which the Atlantic Ocean grew, and is still growing.

The Crust Under the Oceans

The constant generation of new ocean crust along rift zones powers a seemingly endless process that generates new lithosphere that is carried from the crest of the ridges, as if on a conveyor belt. Because of this, scientists have calculated that in about 250 million years, the continents will again join and form a new Pangea as they are pushed by the continually expanding ocean floor. Ocean plates are in contact with land plates at the active boundaries of subduction zones or at passive continental boundaries (continental shelves and slopes). Undersea subduction zones, called ocean trenches, also occur between oceanic plates: these are the deepest places on the planet.

HEIGHTS AND DEPTHS

Deep-ocean basins cover 30 percent of the Earth's surface. The depth of the ocean trenches is greater than the height of the greatest mountain ranges, as shown in the graphic below at left.

29,035 feet (8,850 m)
Highest point
(Mount Everest)

2,900 feet (870 m)
Average land elevation

0 feet (0 m)
Sea level

7,900 feet (2,400 m)
Earth's average elevation

12,240 feet (3,730 m)
Average depth

Greatest depth
(Mariana Trench)
About 36,000 feet (11,000 m)

Inside and Outside the Ridge

The abyssal (deep-ocean) plains of the Atlantic are the flattest surfaces on Earth; for thousands of miles, the elevation varies by only about 10 feet (3 m). The plains are made mostly of sediment. Variations in the ocean's depth are mainly the result of volcanic activity, not just within the mid-Atlantic Ridge but elsewhere as well.

1 ATOLLS
Also called coral reefs, atolls are formations of coral deposited around a volcanic cone in warm seas. They form ring-shaped islands.

2 OCEAN MOUNTS
Isolated volcanic cones. Some rise above the ocean's surface to become islands, such as the Azores.

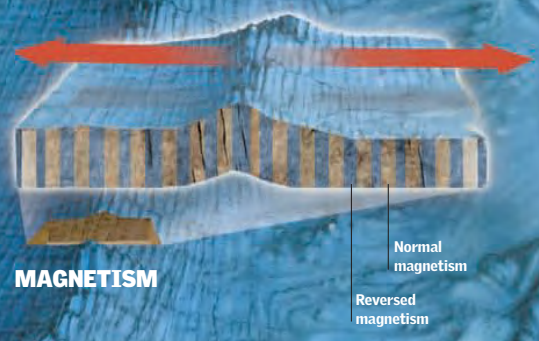
EUROPE

AFRICA

SOUTH AMERICA

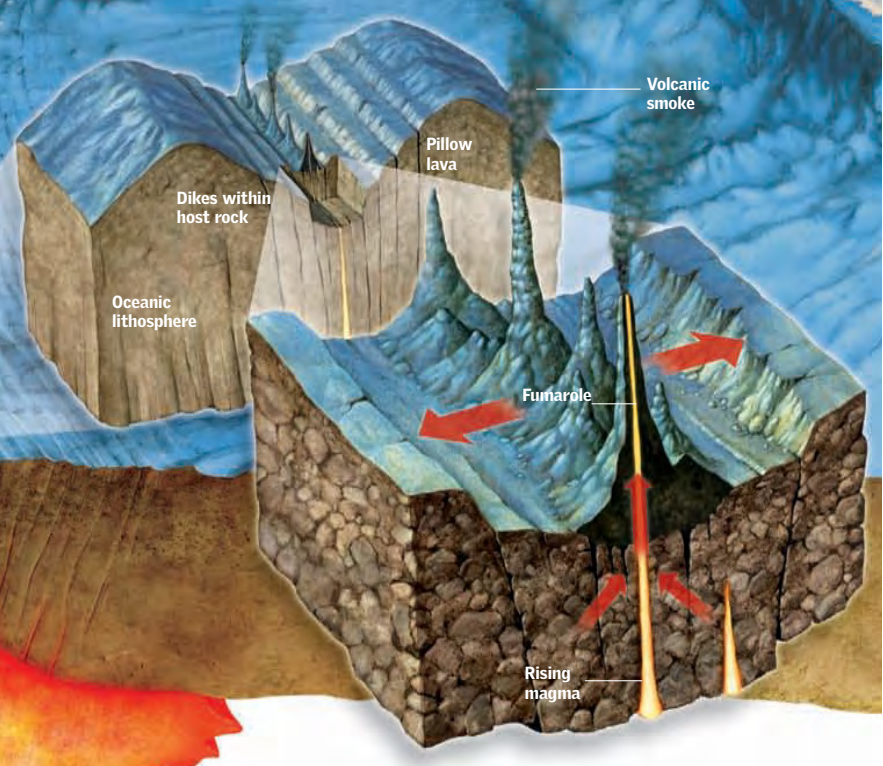
Magnetic Reversals

The Earth's magnetic field changes direction periodically. The magnetic north pole changes places with the magnetic south pole. Rock that solidified during a period of magnetic polarity reversal was magnetized with a polarity opposite that of newly forming rocks. Rocks whose magnetism corresponds to the present direction of the Earth's magnetic field are said to have normal polarity, whereas those with the opposite magnetic polarity are said to have reversed polarity.



How the Mid-Ocean Ridge Was Formed

A spongy layer of rock several dozen miles wide rises above the rift. As the layer fractures and moves away from the fissure, it solidifies into angled blocks that are parallel to the fissure and separated by dikes. Thus the ocean widens as the ridge spreads. The magma exists in a fluid form 2 miles (3.5 km) below the crest of the ridge.



Folding in the Earth's Crust

The movement of tectonic plates causes distortions and breaks in the Earth's crust, especially in convergent plate boundaries. Over millions of years, these distortions produce larger features called folds, which become mountain ranges. Certain characteristic types of terrain give clues about the great folding processes in Earth's geological history.

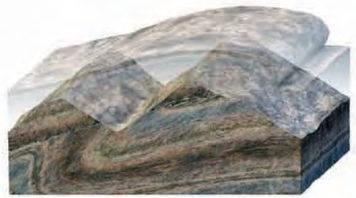
Distortions of the Crust

The crust is composed of layers of solid rock. Tectonic forces, resulting from the differences in speed and direction between plates, make these layers stretch elastically, flow, or break. Mountains are formed in processes requiring millions of years. Then external forces, such as erosion from wind, ice, and water, come into play. If slippage releases rock from the pressure that is deforming it elastically, the rock tends to return to its former state and can cause earthquakes.

1 A portion of the crust subjected to a sustained horizontal tectonic force is met by resistance, and the rock layers become deformed.

2 The outer rock layers, which are often more rigid, fracture and form a fault. If one rock boundary slips underneath another, a thrust fault is formed.

3 The composition of rock layers shows the origin of the folding, despite the effects of erosion.



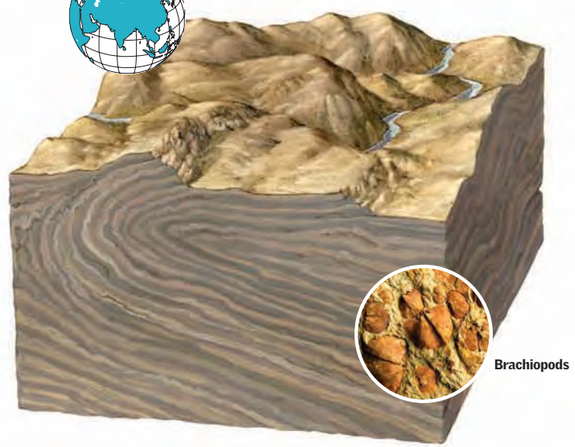
The Three Greatest Folding Events

The Earth's geological history has included three major mountain-building processes, called "orogenies." The mountains created during the first two orogenies (the Caledonian and the Hercynian) are much lower today because they have undergone millions of years of erosion.

MATERIALS Mudstone, slate, and sandstone, in lithified layers.

Trilobites

MATERIALS Mostly granite, slate, amphibolite, gneiss, quartzite, and schist.



Brachiopods

430 Million Years

CALEDONIAN OROGENY

Formed the Caledonian range. Remnants can be seen in Scotland, the Scandinavian Peninsula, and Canada (which all collided at that time).

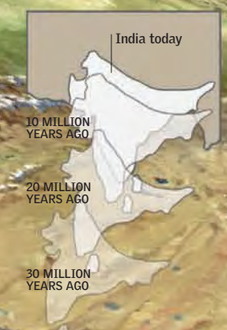
300 Million Years

HERCYNIAN OROGENY

Took place between the late Devonic and the early Permian periods. It was more important than the Caledonian Orogeny. It shaped central and western Europe and produced large veins of iron ore and coal. This orogeny gave rise to the Ural Mountains, the Appalachian range in North America, part of the Andes, and Tasmania.

Formation of the Himalayas

The highest mountains on Earth were formed following the collision of India and Eurasia. The Indian Plate is sliding horizontally underneath the Asiatic Plate. A sedimentary block trapped between the plates is cutting the upper part of the Asiatic Plate into segments that are piling on top of each other. This folding process gave rise to the Himalayan range, which includes the highest mountain on the planet, Mount Everest (29,035 feet [8,850 m]). This deeply fractured section of the old plate is called an accretion prism. At that time, the Asian landmass bent, and the plate doubled in thickness, forming the Tibetan plateau.



Amonites

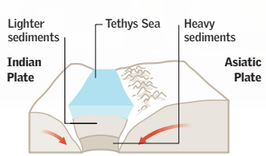
60 MILLION YEARS

ALPINE OROGENY

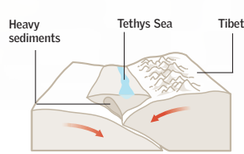
Began in the Cenozoic Era and continues today. This orogeny raised the entire system of mountain ranges that includes the Pyrenees, the Alps, the Caucasus, and even the Himalayas. It also gave the American Rockies and the Andes Mountains their current shape.

MATERIALS
High proportions of sediment in Nepal, batholiths in the Asiatic Plate, and intrusions of new granite: iron, tin, and tungsten.

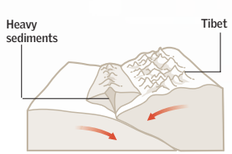
A COLLISION OF CONTINENTS



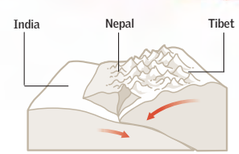
60 MILLION YEARS AGO
The Tethys Sea gives way as the plates approach. Layers of sediment begin to rise.



40 MILLION YEARS AGO
As the two plates approach each other, a subduction zone begins to form.



20 MILLION YEARS AGO
The Tibetan plateau is pushed up by pressure from settling layers of sediment.



THE HIMALAYAS TODAY
The movement of the plates continues to fold the crust, and the land of Nepal is slowly disappearing.

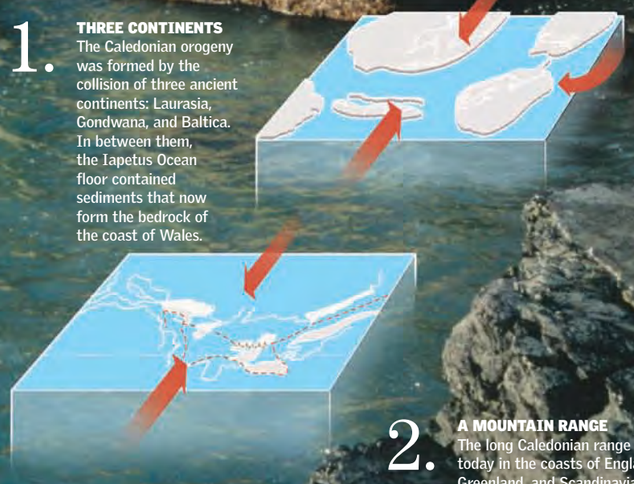
Folds

The force that forms the mountains also molds the rocks within them. As the result of millions of years of pressure, the layers of crust fold into strange shapes. The Caledonian Orogeny, which began 450 million years ago, created a long mountain range that joined the Appalachian mountains of the United States to the Scandinavian peninsula. All of northern England was lifted up during this process. The ancient Iapetus Ocean once lay between the colliding continents. Sedimentary rocks from the bed of this ocean were lifted up, and they have kept the same forms they had in the past.

Silurian

The name of the geological period in which this folding occurred.

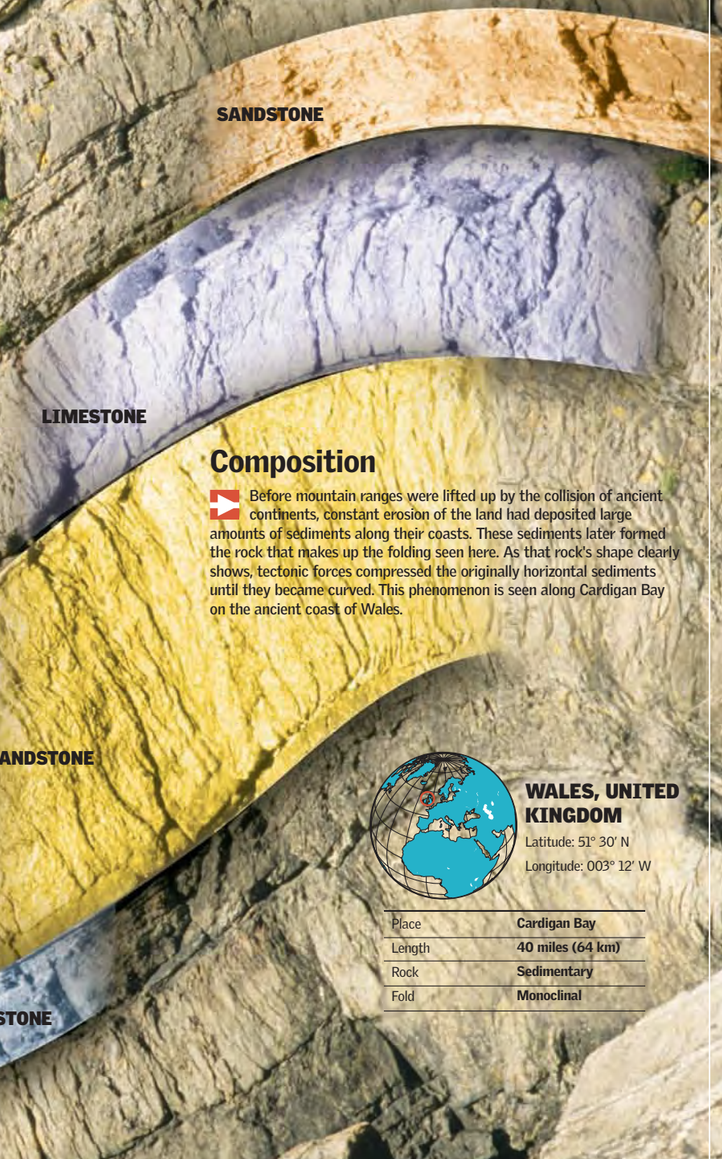
1. THREE CONTINENTS
The Caledonian orogeny was formed by the collision of three ancient continents: Laurasia, Gondwana, and Baltica. In between them, the Iapetus Ocean floor contained sediments that now form the bedrock of the coast of Wales.



440 MILLION YEARS

395 MILLION YEARS

2. A MOUNTAIN RANGE
The long Caledonian range is seen today in the coasts of England, Greenland, and Scandinavia. Since the tectonic movements that created them have ended, they are being worn away and sculpted by constant erosion.



Composition

Before mountain ranges were lifted up by the collision of ancient continents, constant erosion of the land had deposited large amounts of sediments along their coasts. These sediments later formed the rock that makes up the folding seen here. As that rock's shape clearly shows, tectonic forces compressed the originally horizontal sediments until they became curved. This phenomenon is seen along Cardigan Bay on the ancient coast of Wales.

WALES, UNITED KINGDOM
Latitude: 51° 30′ N
Longitude: 003° 12′ W

Place	**Cardigan Bay**
Length	**40 miles (64 km)**
Rock	**Sedimentary**
Fold	**Monoclinal**

When the Faults Resound

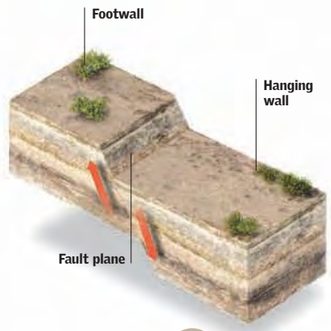
Faults are small breaks that are produced along the Earth's crust. Many, such as the San Andreas fault, which runs through the state of California, can be seen readily. Others, however, are hidden within the crust. When a fault fractures suddenly, an earthquake results. Sometimes fault lines can allow magma from lower layers to break through to the surface at certain points, forming a volcano.

Relative Movement Along Fault Lines

Fault borders do not usually form straight lines or right angles; their direction along the surface changes. The angle of vertical inclination is called "dip." The classification of a fault depends on how the fault was formed and on the relative movement of the two plates that form it. When tectonic forces compress the crust horizontally, a break causes one section of the ground to push above the other. In contrast, when the two sides of the fault are under tension (pulled apart), one side of the fault will slip down the slope formed by the other side of the fault.

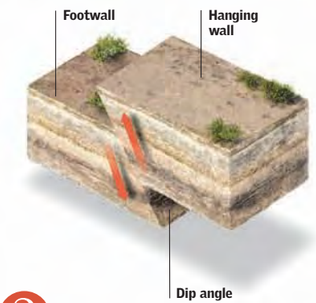
1 Normal Fault

This fault is the product of horizontal tension. The movement is mostly vertical, with an overlying block (the hanging wall) moving downward relative to an underlying block (the footwall). The fault plane typically has an angle of 60 degrees from the horizontal.



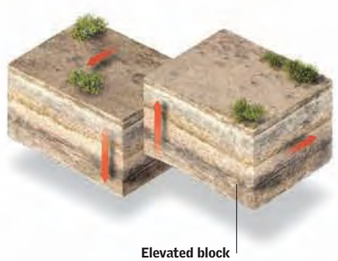
2 Reverse Fault

This fault is caused by a horizontal force that compresses the ground. A fracture causes one portion of the crust (the hanging wall) to slide over the other (the footwall). Thrust faults (see pages 18-19), are a common form of reverse fault that can extend up to hundreds of miles. However, reverse faults with a dip greater than 45° are usually only a few yards long.



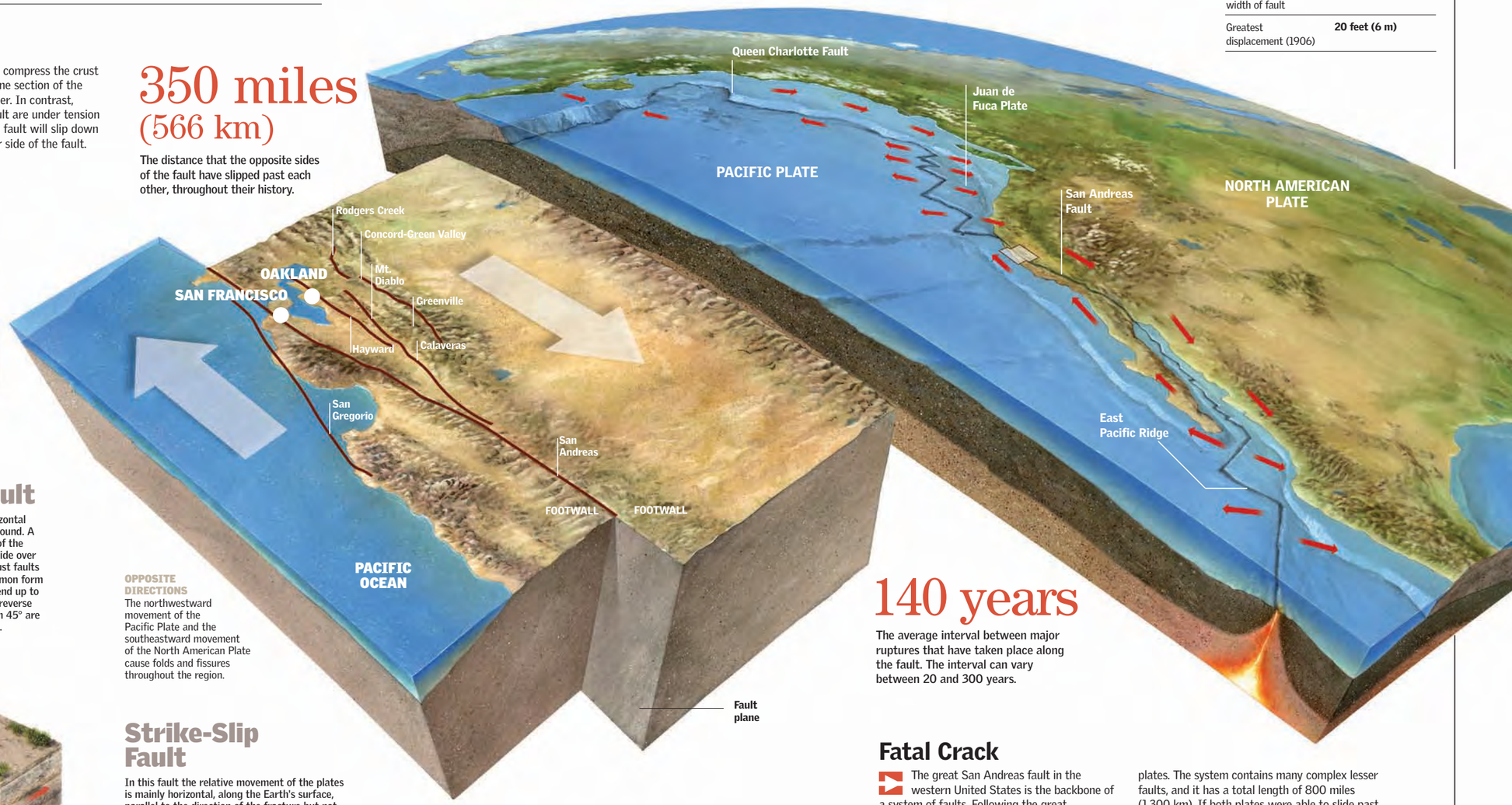
3 Oblique-Slip Fault

This fault has horizontal as well as vertical movements. Thus, the relative displacement between the edges of the fault can be diagonal. In the oldest faults, erosion usually smoothes the differences in the surrounding terrain, but in more recent faults, cliffs are formed. Transform faults that displace mid-ocean ridges are a specific example of oblique-slip faults.



350 miles (566 km)

The distance that the opposite sides of the fault have slipped past each other, throughout their history.



OPPOSITE DIRECTIONS
The northwestward movement of the Pacific Plate and the southeastward movement of the North American Plate cause folds and fissures throughout the region.

Strike-Slip Fault

In this fault the relative movement of the plates is mainly horizontal, along the Earth's surface, parallel to the direction of the fracture but not parallel to the fault plane. Transform faults between plates are usually of this type. Rather than a single fracture, they are generally made up of a system of smaller fractures, slanted from a centerline and more or less parallel to each other. The system can be several miles wide.

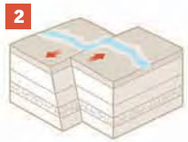
Streambeds Diverted by Tectonic Movement

Through friction and surface cracking, a transform fault creates transverse faults and, at the same time, alters them with its movement. Rivers and streams distorted by the San Andreas fault have three characteristic forms: streambeds with tectonic displacement, diverted streambeds, and streambeds with an orientation that is nearly oblique to the fault.

1

Diverted Streambed
The stream changes course as a result of the break.

2



Displaced Streambed
The streambed looks "broken" along its fault line.

WEST COAST OF THE UNITED STATES

Length of California	**770 miles (1,240 km)**
Length of fault	**800 miles (1,300 km)**
Maximum width of fault	**60 miles (100 km)**
Greatest displacement (1906)	**20 feet (6 m)**

140 years

The average interval between major ruptures that have taken place along the fault. The interval can vary between 20 and 300 years.

PAST AND FUTURE
Some 30 million years ago, the Peninsula of California was west of the present coast of Mexico. Thirty million years from now, it is possible that it may be some distance off the coast of Canada.

Fatal Crack

The great San Andreas fault in the western United States is the backbone of a system of faults. Following the great earthquake that leveled San Francisco in 1906, this system has been studied more than any other on Earth. It is basically a horizontal transform fault that forms the boundary between the Pacific and North American tectonic plates. The system contains many complex lesser faults, and it has a total length of 800 miles (1,300 km). If both plates were able to slide past each other smoothly, no earthquakes would result. However, the borders of the plates are in contact with each other. When the solid rock cannot withstand the growing strain, it breaks and unleashes an earthquake.

Volcanoes

MOUNT ETNA
With a height of 10,810 feet (3,295 m), Etna is the largest and most active volcano in Europe.

FLAMING FURNACE 26-27
CLASSIFICATION 28-29
FLASH OF FIRE 30-31
MOUNT ST. HELENS 32-33
KRAKATOA 34-35
AFTERMATH OF FURY 36-37
JETS OF WATER 38-39
RINGS OF CORAL 40-41
FROZEN FLAME 42-43

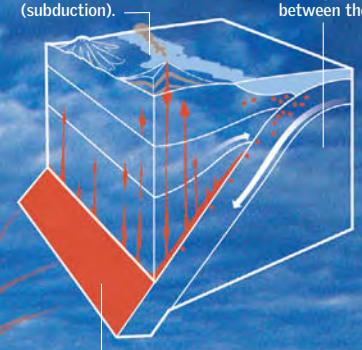
Mount Etna has always been an active volcano, as seen from the references to its activity that have been made throughout history. It could be said that the volcano has not given the beautiful island of Sicily a moment's rest. The Greek philosopher Plato was the first to study Mount Etna. He traveled to Italy especially to see it up close, and he subsequently described how the lava cooled. Today Etna's periodic eruptions continue to draw hundreds of thousands of tourists, who enjoy the spectacular fireworks produced by its red-hot explosions. This phenomenon is visible from the entire east coast of Sicily because of the region's favorable weather conditions and the constant strong winds. ●

Flaming Furnace

Volcanoes are among the most powerful manifestations of our planet's dynamic interior. The magma they release at the Earth's surface can cause phenomena that devastate surrounding areas: explosions, enormous flows of molten rock, fire and ash that rain from the sky, floods, and mudslides. Since ancient times, human beings have feared volcanoes, even seeing their smoking craters as an entrance to the underworld. Every volcano has a life cycle, during which it can modify the topography and the climate and after which it becomes extinct.

MOUNTAIN-RANGE VOLCANOES

Many volcanoes are caused by phenomena occurring in subduction zones along convergent plate boundaries.



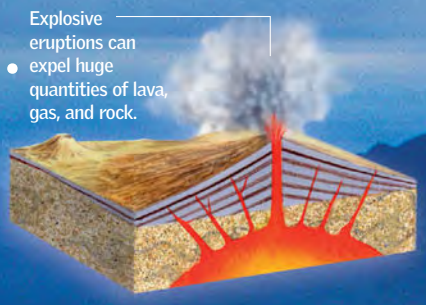
1 When two plates converge, one moves under the other (subduction).

2 The rock melts and forms new magma. Great pressure builds up between the plates.

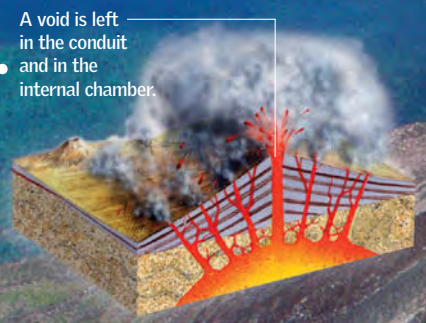
3 The heat and pressure in the crust force the magma to seep through cracks in the rock and rise to the surface, causing volcanic eruptions.

LIFE AND DEATH OF A VOLCANO: THE FORMATION OF A CALDERA

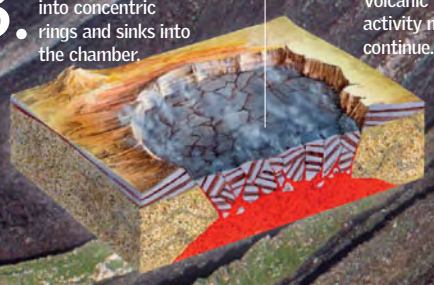
1. Explosive eruptions can expel huge quantities of lava, gas, and rock.



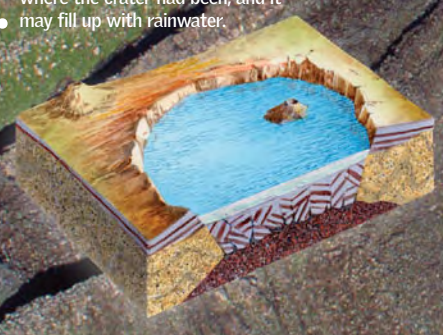
2. A void is left in the conduit and in the internal chamber.



3. The cone breaks up into concentric rings and sinks into the chamber. Volcanic activity may continue.



4. A depression, or caldera, forms where the crater had been, and it may fill up with rainwater.



ERUPTION OF LAVA

CLOUD OF ASH

STREAMS OF LAVA flow down the flanks of the volcano.

VOLCANIC CONE Made of layers of igneous rock, formed from previous eruptions. Each lava flow adds a new layer.

MAIN CONDUIT The pipe through which magma rises. It connects the magma chamber with the surface.

SEEPAGE OF GROUNDWATER

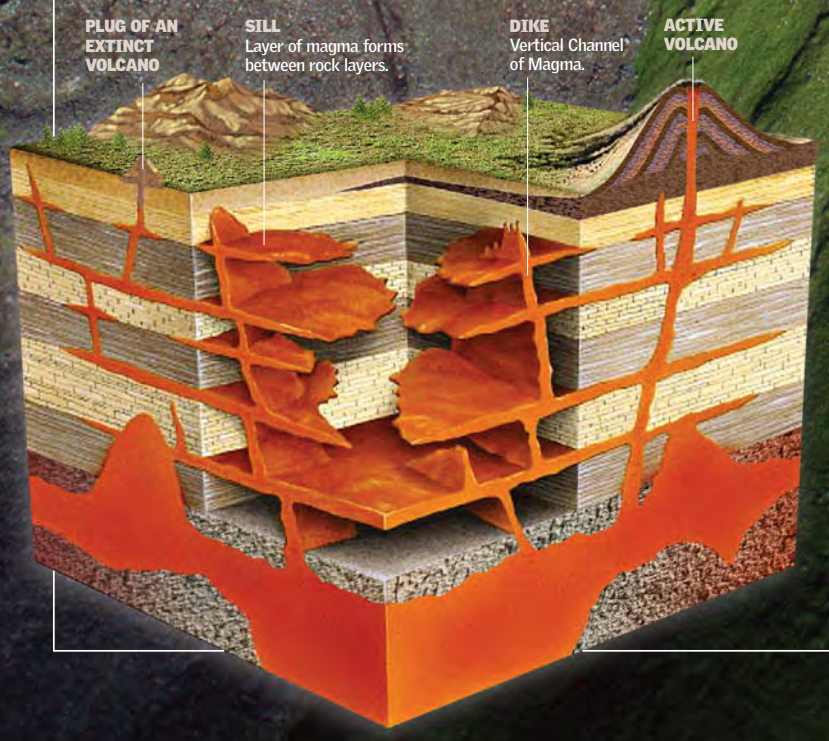
CRATER Depression or hollow from which eruptions expel magmatic materials (lava, gas, steam, ash, etc.)

PARASITIC VOLCANO Composite volcanic cones have more than one crater.

SECONDARY CONDUIT

EXTINCT CONDUIT

INTRUSION OF MAGMA



Magma can reach the surface, or it can stay below ground and exert pressure between the layers of rock. These seepages of magma have various names.

MAGMA CHAMBER Mass of molten rock at temperatures that may exceed

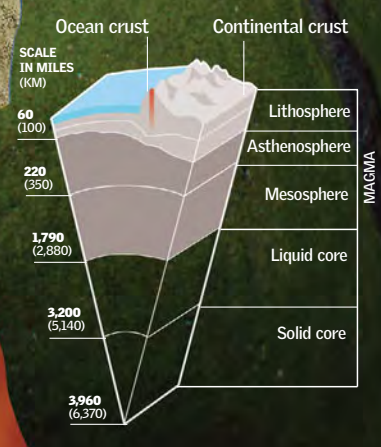
2,000° F

(1,100° C)

In an active volcano, magma in the chamber is in constant motion because of fluctuations of temperature and pressure (convection currents).

UNDER THE VOLCANO

In its ascent to the surface, the magma may be blocked in various chambers at different levels of the lithosphere.

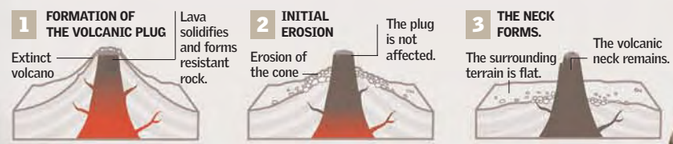


Classification

No two volcanoes on Earth are exactly alike, although they have characteristics that permit them to be studied according to six basic types: shield volcanoes, cinder cones, stratovolcanoes, lava cones, fissure volcanoes, and calderas. A volcano's shape depends on its origin, how the eruption began, processes that accompany the volcanic activity, and the degree of danger the volcano poses to life in surrounding areas.

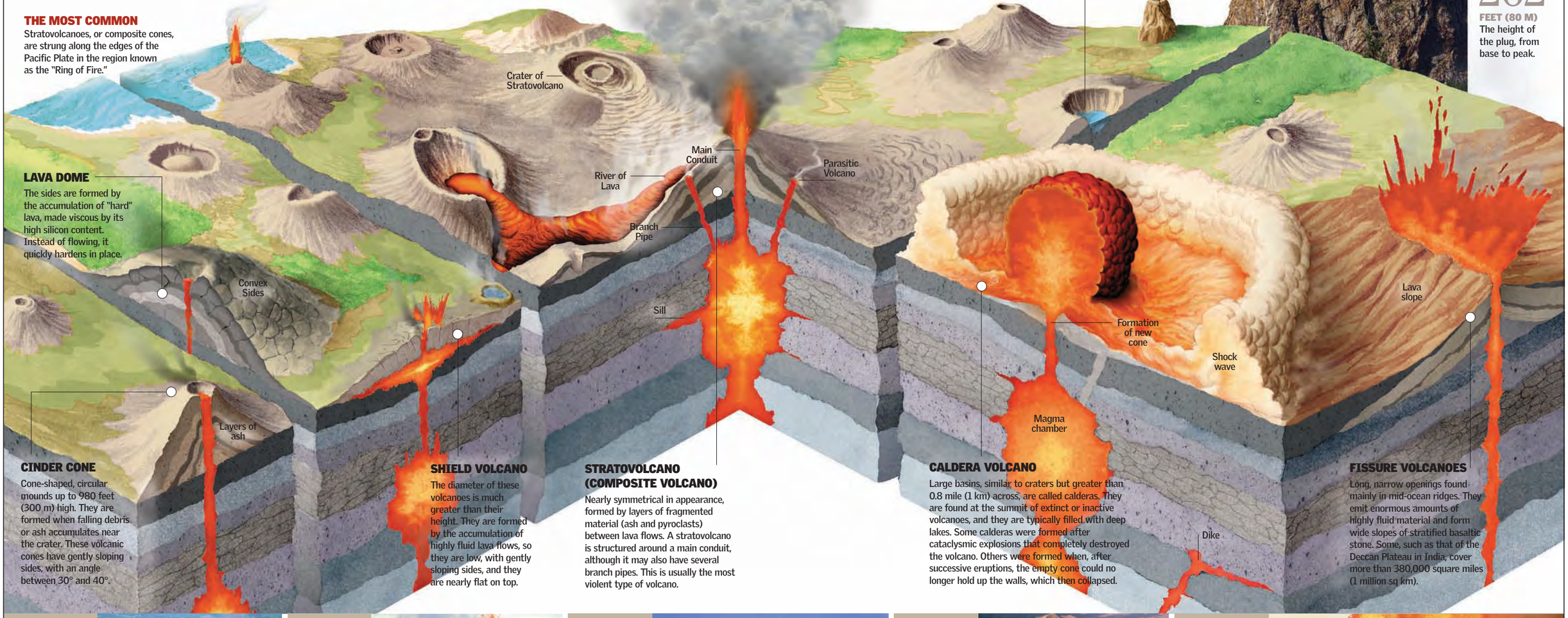
THE MOST COMMON
Stratovolcanoes, or composite cones, are strung along the edges of the Pacific Plate in the region known as the "Ring of Fire."

IGNEOUS INTRUSIONS: A PECULIAR PROFILE



CHAPEL OF ST. MICHAEL
Built in Le Puy, France, on top of a volcanic neck of hard rock that once sealed the conduit of a volcano. The volcano's cone has long since been worn away by erosion; the lava plug remains.

262
FEET (80 M)
The height of the plug, from base to peak.



LAVA DOME
The sides are formed by the accumulation of "hard" lava, made viscous by its high silicon content. Instead of flowing, it quickly hardens in place.

CINDER CONE
Cone-shaped, circular mounds up to 980 feet (300 m) high. They are formed when falling debris or ash accumulates near the crater. These volcanic cones have gently sloping sides, with an angle between 30° and 40°.

SHIELD VOLCANO
The diameter of these volcanoes is much greater than their height. They are formed by the accumulation of highly fluid lava flows, so they are low, with gently sloping sides, and they are nearly flat on top.

STRATOVOLCANO (COMPOSITE VOLCANO)
Nearly symmetrical in appearance, formed by layers of fragmented material (ash and pyroclasts) between lava flows. A stratovolcano is structured around a main conduit, although it may also have several branch pipes. This is usually the most violent type of volcano.

CALDERA VOLCANO
Large basins, similar to craters but greater than 0.8 mile (1 km) across, are called calderas. They are found at the summit of extinct or inactive volcanoes, and they are typically filled with deep lakes. Some calderas were formed after cataclysmic explosions that completely destroyed the volcano. Others were formed when, after successive eruptions, the empty cone could no longer hold up the walls, which then collapsed.

FISSURE VOLCANOES
Long, narrow openings found mainly in mid-ocean ridges. They emit enormous amounts of highly fluid material and form wide slopes of stratified basaltic stone. Some, such as that of the Deccan Plateau in India, cover more than 380,000 square miles (1 million sq km).

MOUNT ILAMATEPEC
Cinder cone located 45 miles (65 km) west of the capital of El Salvador. Its last recorded eruption was in October 2005.

MOUNT KILAUEA
Shield volcano in Hawaii. One of the most active shield volcanoes on Earth.

MOUNT FUJI
Composite volcano 12,400 feet (3,776 m) high, the highest in Japan. Its last eruption was in 1707.

CALDERA BLANCA
Located on Lanzarote, Canary Islands, in the fissure zone known as the Montañas de Fuego (Fire Mountains).

MAUNA ULU
Fissure volcano, about 5 miles (8 km) from the top of Kilauea (Hawaii). This is one of the most active volcanoes in the central Pacific.

Flash of Fire

A volcanic eruption is a process that can last from a few hours to several decades. Some are devastating, but others are mild. The severity of the eruption depends on the dynamics between the magma, dissolved gas, and rocks within the volcano. The most potent explosions often result from thousands of years of accumulation of magma and gas, as pressure builds up inside the chamber. Other volcanoes, such as Stromboli and Etna, reach an explosive point every few months and have frequent emissions.

HOW IT HAPPENS

3. THE ESCAPE

When the mounting pressure of the magma becomes greater than the materials between the magma and the floor of the volcano's crater can bear, these materials are ejected.

2. IN THE CONDUIT

A solid layer of fragmented materials blocks the magma that contains the volatile gases. As the magma rises and mixes with volatile gases and water vapor, the pockets of gases and steam that form give the magma its explosive power.

1. IN THE CHAMBER

There is a level at which liquefaction takes place and at which rising magma, under pressure, mixes with gases in the ground. The rising currents of magma increase the pressure, hastening the mixing.

4. PYROCLASTIC PRODUCTS

In addition to lava, an eruption can eject solid materials called pyroclasts. Volcanic ash consists of pyroclastic material less than 0.08 inch (2 mm) in size. An explosion can even expel granite blocks.

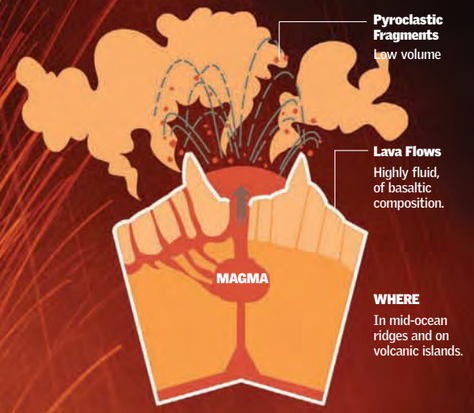
BOMB	2.5 inches (64 mm) and up
LAPILLI	0.08 to 2.5 inches (2 mm to 64 mm)
ASH	Up to 0.08 inch (2 mm)

5. LAVA FLOWS

On the volcanic island of Hawaii, nonerupting flows of lava abound. Local terms for lava include "aa," viscous lava flows that sweep away sediments, and "pahoehoe," more fluid lava that solidifies in soft waves.

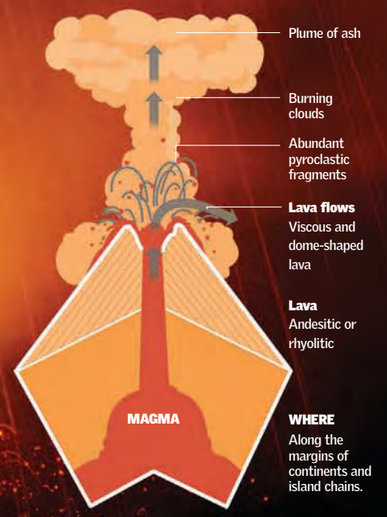
EFFUSIVE ACTIVITY

Mild eruptions with a low frequency of explosions. The lava has a low gas content, and it flows out of openings and fissures.

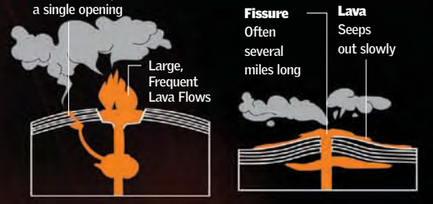


EXPLOSIVE ACTIVITY

Comes from the combination of high levels of gas with relatively viscous lava, which can produce pyroclasts and build up great pressure. Different types of explosions are distinguished based on their size and volume. The greatest explosions can raise ash into a column several miles high.



TYPES OF EFFUSIVE ERUPTION



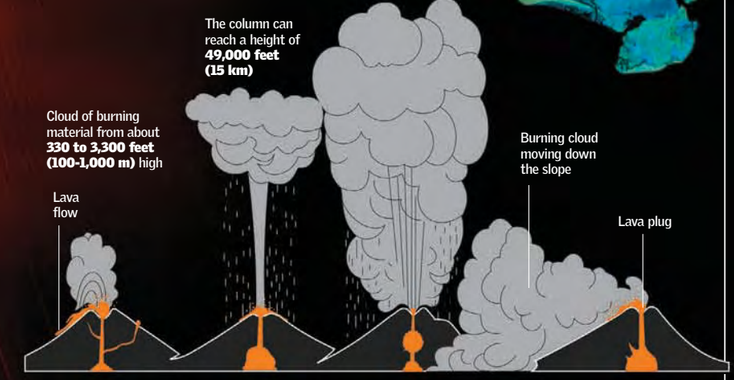
HAWAIIAN

Volcanoes such as Mauna Loa and Kilauea expel large amounts of basaltic lava with a low gas content, so their eruptions are very mild. They sometimes emit vertical streams of bright lava ("fountains of fire") that can reach up to 330 feet (100 m) in height.

FISSURE

Typical in ocean rift zones, fissures are also found on the sides of composite cones such as Etna (Italy) or near shield volcanoes (Hawaii). The greatest eruption of this type was that of Laki, Iceland, in 1783: 2.9 cubic miles (12 cu km) of lava was expelled from a crack 16 miles (25 km) long.

TYPES OF EXPLOSIVE ERUPTION



STROMBOLIAN

The volcano Stromboli in Sicily, Italy, gave its name to these high-frequency eruptions. The relatively low volume of expelled pyroclasts allows these eruptions to occur approximately every five years.

VULCANIAN

Named after Vulcano in Sicily. As eruptions eject more material and become more explosive, they become less frequent. The 1985 eruption of Nevado del Ruiz expelled tens of thousands of cubic yards of lava and ash.

VESUVIAN

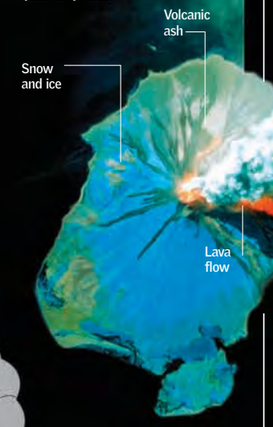
Also called Plinian, the most violent explosions raise columns of smoke and ash that can reach into the stratosphere and last up to two years, as in the case of Krakatoa (1883).

PELEAN

A plug of lava blocks the crater and diverts the column to one side after a large explosion. As with Mt. Pelée in 1902, the pyroclastic flow and lava are violently expelled down the slope in a burning cloud that sweeps away everything in its path.

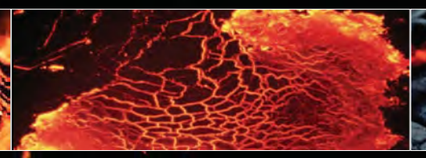
FROM OUTER SPACE

A photo of the eruption of Mt. Augustine in Alaska, taken by the Landsat 5 satellite hours after the March 27, 1986, eruption.



LAVA FLOW MT. KILAUEA, HAWAII

LAKE OF LAVA MAKA-O-PUHL, HAWAII



COOLED LAVA (PAHOEHOE) MT. KILAUEA, HAWAII

Mount St. Helens

Within the territory of the United States, active volcanoes are not limited to exotic regions such as Alaska or Hawaii. One of the most explosive volcanoes in North America is in Washington state. Mount St. Helens, after a long period of calm, had an eruption of ash and vapor on May 18, 1980. The effects were devastating: 57 people were killed, and lava flows destroyed trees over an area of 232 square miles (600 sq km). The lake overflowed, causing mudslides that destroyed houses and roads. The area will need a century to recover.

Cut Top
Like the cork in a bottle of champagne, the top of the mountain burst off because of pressure from the magma.

In the eruption Mount St. Helens lost its conical stratovolcano shape and became a caldera.

BEFORE THE ERUPTION
The symmetrical cone, surrounded by forest and prairies, was admired as the American Fuji. The eruption left a horseshoe-shaped caldera, surrounded by devastation.

DURING THE EXPLOSION
The energy released was the equivalent of 500 nuclear bombs. The top of the mountain flew off like the cap of a shaken bottle of soda.

8 miles
13 km
Pulverized and incinerated by the force of the lava and the pyroclastic flow. Temperatures rose above 1,110° F (600° C).

232 SQUARE MILES
600 sq km
SURFACE DESTRUCTION
The effects were devastating: 250 houses, 47 bridges, rail lines, and 190 miles (300 km) of highway were lost.

15 miles
24 km
Range of the shock wave from the pyroclastic flow. The heat and ash left acres of forest completely destroyed.

The Forest
Burned trees covered with ash, several miles from the volcano

OLYMPIA WASHINGTON STATE

Type of Volcano	Stratovolcano
Size of Base	5.9 mi (9.5 km)
Type of Activity	Explosive
Type of Eruption	Plinian
Most Recent Eruptions	1980, 1998, 2004
Fatalities	57

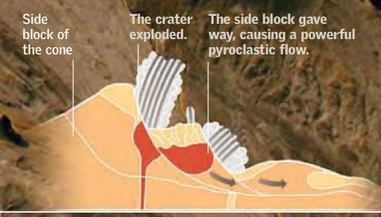
Warning Signs

Two months before the great explosion, Mount St. Helens gave several warning signs: a series of seismic movements, small explosions, and a swelling of the mountain's north slope, caused by magma rising toward the surface. Finally on May 18, an earthquake caused a landslide that carried away the top of the volcano. Later, several collapses at the base of the column caused numerous pyroclastic flows with temperatures of nearly 1,300° F (700° C).

1. 00:00
SWELLING
The uninterrupted flow of magma toward the volcano's surface caused the north slope of the mountain to swell, and later collapse in an avalanche.

2. 00:40
PRESSURE ON THE NORTH SLOPE
The swelling of the mountain was no doubt caused by the first eruption, almost two months before the final explosion.

3. 00:50
INITIAL ERUPTIONS
The north slope gave way to the great pressure of the magma in an explosive eruption. The lava traveled 16 miles (25 km) at 246 feet (75 m) per second.



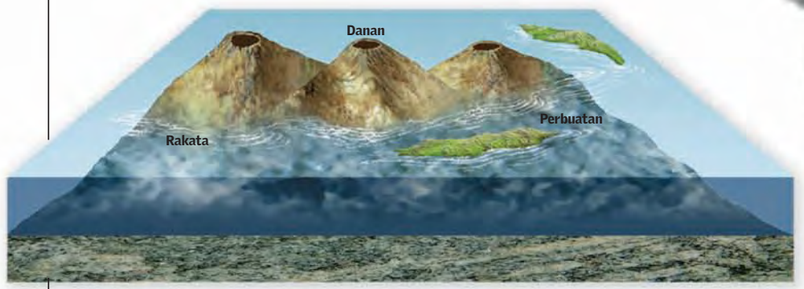
4. 00:60
EXPLOSION AND VERTICAL COLLAPSE
At the foot of the volcano, a valley 640 feet (195 m) deep was buried in volcanic material. Over 10 million trees were destroyed.

Krakatoa

In early 1883, Krakatoa was just one of many volcanic islands on Earth. It was located in the Straits of Sundra, between Java and Sumatra in the Dutch East Indies, now known as Indonesia. It had an area of 10.8 square miles (28 sq km) and a central peak with a height of 2,690 feet (820 m). In August 1883, the volcano exploded, and the island was shattered in the largest natural explosion in history. ●

The Island That Exploded

Krakatoa was near the subduction zone between the Indo-Australian and Eurasian plates. The island's inhabitants were unconcerned about the volcano because the most recent previous eruption had been in 1681. Some even thought the volcano was extinct. On the morning of Aug. 27, 1883, the island exploded. The explosion was heard as far away as Madagascar. The sky was darkened, and the tsunamis that followed the explosion were up to 130 feet (40 m) high.



1 BEFORE
In May the volcano began showing signs in the form of small quakes and spouting vapor, smoke, and ash. None of this served to warn of the terrible explosion to come, and some even took trips to see the volcano's "pyrotechnics."

2 DURING
At 5:30 a.m. the island burst from the accumulated pressure, opening a crater 820 feet (250 m) deep. Water immediately rushed in, causing a gigantic tsunami.

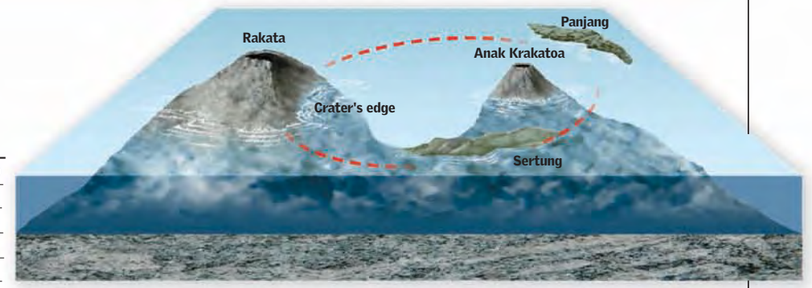
130 feet (40 m)
The height of the tsunami waves, which traveled at 700 miles per hour (1,120 km/h).

34 miles (55 km)
The height of the column of ash.

PYROCLASTICS
The pyroclastic flows were so violent that, according to the descriptions of sailors, they reached up to 37 miles (80 km) from the island.

KRAKATOA
Latitude 6° 06′ S
Longitude 105° 25′ E

Surface Area	**10.8 square miles (28 sq km)**
Remaining Surface Area	**3 square miles (8 sq km)**
Range of the Explosion	**2,900 miles (4,600 km)**
Range of Debris	**1,550 miles (2,500 km)**
Tsunami Victims	**36,000**



3 AFTER
A crater nearly 4 miles (6.4 km) in diameter was left where the volcano had been. About 1927, new volcanic activity was observed in the area. In 1930, a cone emerged. Anak Krakatoa ("daughter of Krakatoa") appeared in 1952; it grows at a rate of nearly 15 feet (4.5 m) per year.

FRACTION
Two thirds of the island was destroyed, and only a part of Rakata survived the explosion.

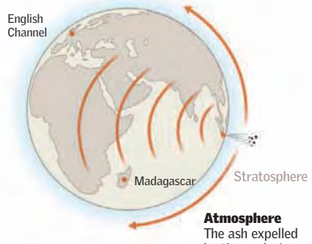
Aftereffects

The ash released into the atmosphere left enough particles suspended in the air to give the Moon a blue tinge for years afterward. The Earth's average temperature also decreased.

Long-Term Effects

WATER LEVEL
The water level fluctuated as far away as the English Channel.

PRESSURE WAVE
The atmospheric pressure wave went around the world seven times.

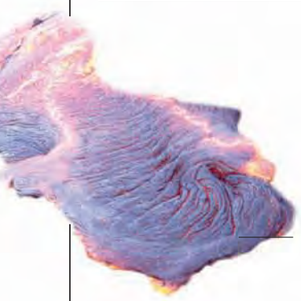


Atmosphere
The ash expelled by the explosion lingered for years

500 MEGATONS
The energy released, equivalent to 25,000 atomic bombs such as the one dropped on Hiroshima.

Aftermath of Fury

When a volcano becomes active and explodes, it sets in motion a chain of events beyond the mere danger of the burning lava that flows down its slopes. Gas and ash are expelled into the atmosphere and affect the local climate. At times they interfere with the global climate, with more devastating effects. The overflow of lakes can also cause mudslides called lahars, which bury whole cities. In coastal areas, lahars can cause tsunamis.



LAVA FLOWS

In volcanoes with calderas, low-viscosity lava can flow without erupting, as with the Laki fissures in 1783. Low-viscosity lava drips with the consistency of clear honey. Viscous lava is thick and sticky, like crystallized honey.

LAVA IN VOLCANO NATIONAL PARK, HAWAII

CINDER CONE

Cone with walls of hardened lava.

As the lava flows upward, the cone explodes.

MOLDS OF TREES

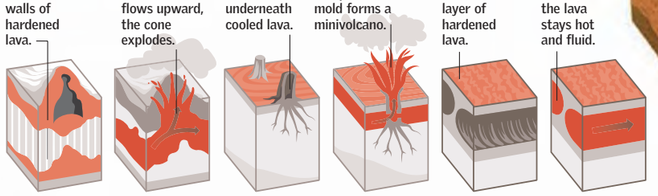
Burned tree underneath cooled lava.

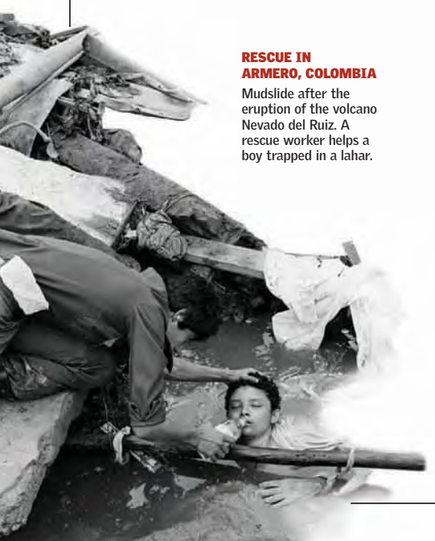
The petrified mold forms a minivolcano.

LAVA TUBES

Outer layer of hardened lava.

Inside, the lava stays hot and fluid.





RESCUE IN ARMERO, COLOMBIA

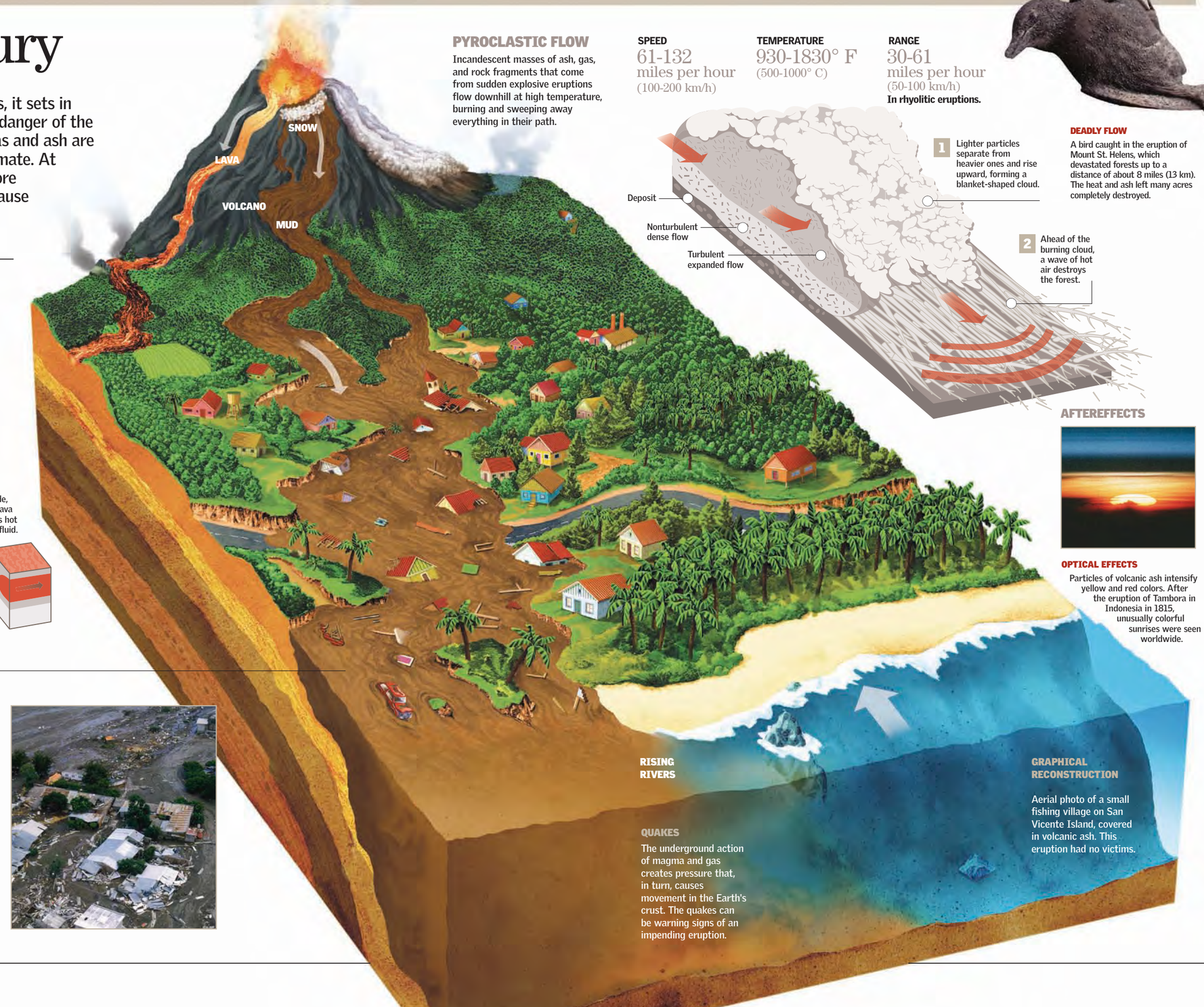
Mudslide after the eruption of the volcano Nevado del Ruiz. A rescue worker helps a boy trapped in a lahar.

MUDSLIDES OR LAHARS

Rain mixed with snow and melted by the heat, along with tremors and overflowing lakes, can cause mudslides called "lahars." These can be even more destructive than the eruption itself, destroying everything in their path as they flow downhill. They occur frequently on high volcanoes that have glaciers on their summit.

ARMERO FROM ABOVE

On Nov. 13, 1985, the city of Armero, Colombia, was devastated by mudslides from the eruption of the volcano Nevado del Ruiz.



PYROCLASTIC FLOW

Incandescent masses of ash, gas, and rock fragments that come from sudden explosive eruptions flow downhill at high temperature, burning and sweeping away everything in their path.

SPEED
61-132 miles per hour (100-200 km/h)

TEMPERATURE
930-1830° F (500-1000° C)

RANGE
30-61 miles per hour (50-100 km/h)
In rhyolitic eruptions.

DEADLY FLOW

A bird caught in the eruption of Mount St. Helens, which devastated forests up to a distance of about 8 miles (13 km). The heat and ash left many acres completely destroyed.

AFTEREFFECTS

OPTICAL EFFECTS

Particles of volcanic ash intensify yellow and red colors. After the eruption of Tambora in Indonesia in 1815, unusually colorful sunrises were seen worldwide.

RISING RIVERS

QUAKES

The underground action of magma and gas creates pressure that, in turn, causes movement in the Earth's crust. The quakes can be warning signs of an impending eruption.

GRAPHICAL RECONSTRUCTION

Aerial photo of a small fishing village on San Vicente Island, covered in volcanic ash. This eruption had no victims.

Jets of Water

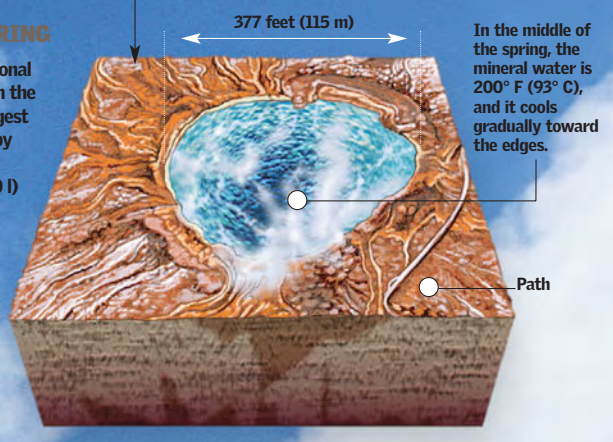
Geysers are intermittent spurts of hot water that can shoot up dozens of yards into the sky. Geysers form in the few regions of the planet with favorable hydrogeology, where the energy of past volcanic activity has left water trapped in subterranean rocks. Days or weeks may pass between eruptions. Most of these spectacular phenomena are found in Yellowstone National Park (U.S.) and in northern New Zealand. ●

PRINCIPAL GEOTHERMAL FIELDS

There are some 1,000 geysers worldwide, and 50 percent are in Yellowstone National Park (U.S.).

GRAND PRISMATIC SPRING

This spring, in Yellowstone National Park, is the largest hot spring in the United States and the third largest in the world. It measures 246 by 377 feet (75 by 115 m), and it emits about 530 gallons (2,000 l) of water per minute. It has a unique color: red mixed with yellow and green.



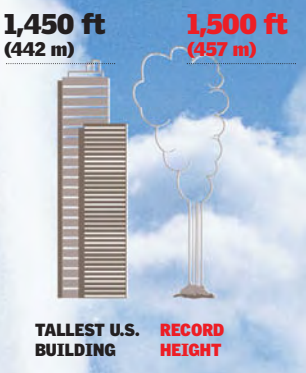
DISCHARGE

530 gallons (2,000 l)

OF WATER PER MINUTE

RECORD HEIGHT

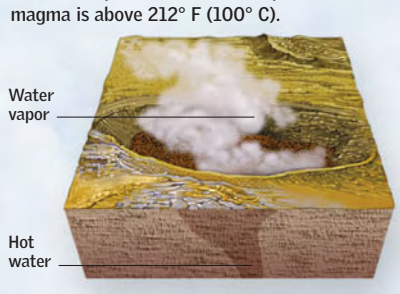
In 1904, New Zealand's Waimangu geyser (now inactive) emitted a record-setting spurt of water. In 1903, four tourists lost their lives when they unknowingly came too close to the geyser.



OTHER POSTVOLCANIC ACTIVITY

FUMAROLE

This is a place where there is a constant emission of water vapor because the temperature of the magma is above 212° F (100° C).

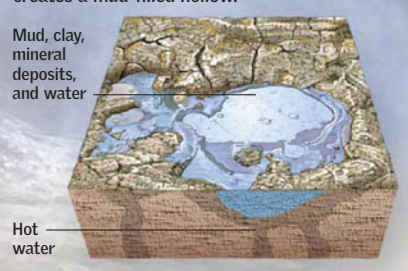


SOLFATARA

The thermal layers emit sulfur and sulfurous anhydride.

MUD BASIN

These basins produce their own mud; sulfuric acid corrodes the rocks on the surface and creates a mud-filled hollow.



The eruptive cycle

5. THE CYCLE REPEATS

When the water pressure in the chambers is relieved, the spurt of water abates, and the cycle repeats. Water builds up again in cracks of the rock and in permeable layers.

On average, a geyser can expel up to 7,900 gallons (30,000 l) OF WATER

4. SPURTING SPRAY

The water spurts out of the cone at irregular intervals. The lapse between spurts depends on the time it takes for the chambers to fill up with water, come to a boil, and produce steam.

The average height reached of the spurt of water is about 148 feet (45 m)

3. BURSTING FORTH

The water rises by convection and spurts out the main vent to the chimney or cone. The deepest water becomes steam and explodes outward.

CONVECTION FORCES

This is a phenomenon equivalent to boiling water.

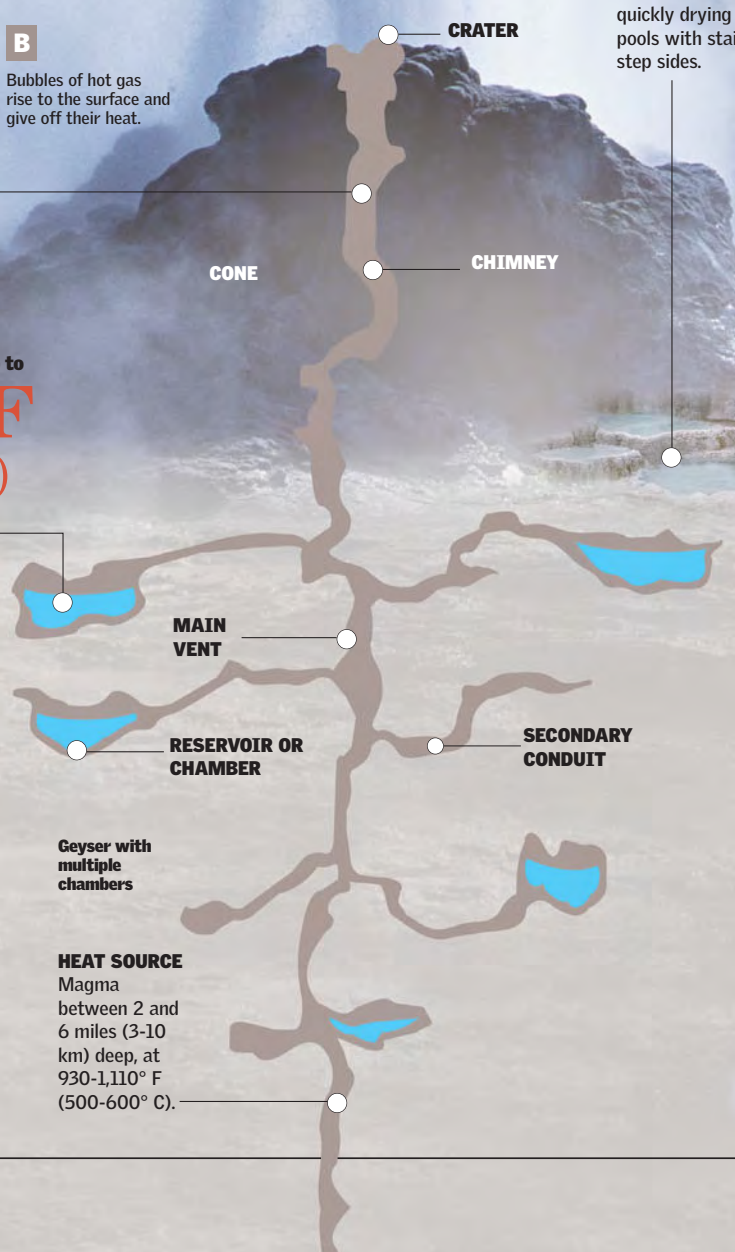
2. MOUNTING PRESSURE

The underground chambers fill with water, steam, and gas at high temperatures, and these are then expelled through secondary conduits to the main vent.

1. HEATED WATER

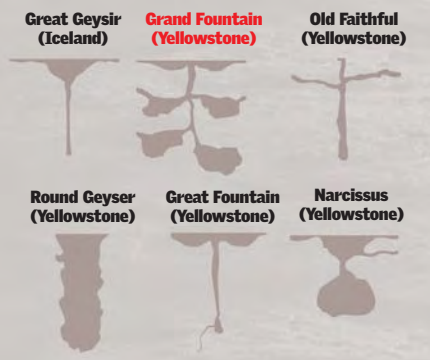
Thousands of years after the eruption of a volcano, the area beneath it is still hot. The heat rising from the magma chambers warms water that filters down from the soil. In the subsoil, the water can reach temperatures of up to 518° F (270° C), but pressure from cooler water above keeps it from boiling.

Temperatures up to 194°F (90° C)



MORPHOLOGY OF THE CHAMBERS

The heat of a magma chamber warms water in the cavity, the chamber fills, and the water rises to the surface. The pressure in the cavity is released, and the water suddenly boils and spurts out.



MINERAL SPRINGS

Their water contains many minerals, known since antiquity for their curative properties. Among other substances, they include sodium, potassium, calcium, magnesium, silicon oxide, chlorine, sulfates (SO4), and carbonates (HCO3). They are very helpful for rheumatic illnesses.

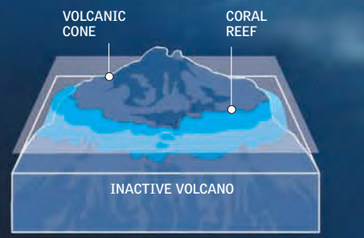
Steam Energy

In Iceland, geothermic steam is used not only in thermal spas but also to power turbines that generate most of the country's electricity.

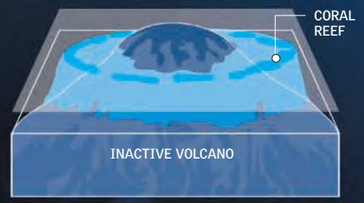
Rings of Coral

In the middle of the ocean, in the tropics, there are round, ring-shaped islands called atolls. They are formed from coral reefs that grew along the sides of ancient volcanoes that are now submerged. As the coral grows, it forms a barrier of reefs that surround the island like a fort. How does the process work? Gradually, volcanic islands sink, and the reefs around them form a barrier. Finally, the volcano is completely submerged; no longer visible, it is replaced by an atoll.

FORMATION OF AN ATOLL



1. THE BEGINNING OF AN ATOLL. The undersea flanks of an extinct volcano are colonized by corals, which continue to grow.



2. THE CORALS GAIN GROUND. As the surrounding reef settles and continues to expand, it becomes a barrier reef that surrounds the summit of the ancient volcano, now inactive.

3. THE ATOLL SOLIDIFIES. Eventually the island will be completely covered and will sink below the water, leaving a ring of growing coral with a shallow lagoon in the middle.

ATOLLS AND VOLCANIC ISLANDS AROUND THE WORLD

Coral reefs are found in the world's oceans, usually between the Tropic of Cancer and the Tropic of Capricorn.

OPTIMAL CONDITIONS

Coral is mainly found in the photic zone (less than 165 feet [50 m] deep), where sunlight reaches the bottom and provides sufficient energy. For reefs to grow, the water temperature should be between 68° and 82° F (20-28° C).

Country	Republic of Kiribati
Ocean	North Pacific
Archipelago	Gilbert Islands
Surface area	10.8 square miles (28 sq km)
Altitude	6.9 ft (2.1 m)

LEGEND
● Town ✪ Capital

REEF LEVELS

CREST
Barrier that protects the shore from waves. Deep grooves and tunnels let seawater inside the reef.

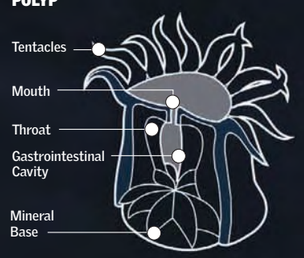
FACE
Branching corals grow here, though colonies can break loose because of the steep slope.

HAWAIIAN ARCHIPELAGO

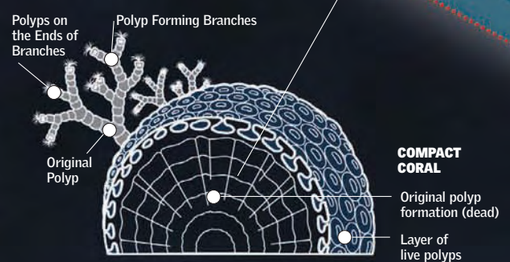
WHAT ARE CORALS?

Corals are formed from the exoskeletons of a group of Cnidarian species. These marine invertebrates have a sexual phase, called a medusa, and an asexual phase, called a polyp. The polyps secrete an outer skeleton composed of calcium carbonate, and they live in symbiosis with one-celled algae.

HARD CORAL POLYP



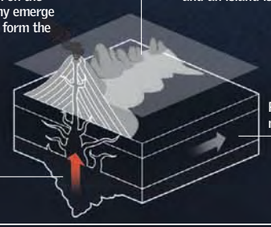
BRANCHING CORAL

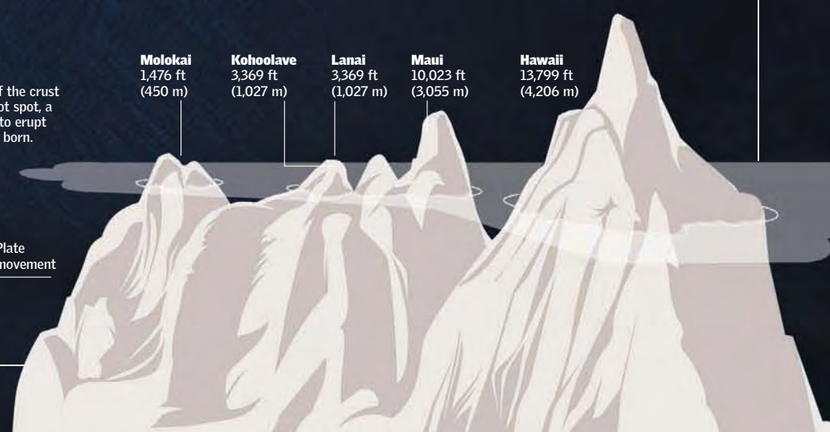


FORMATION OF A VOLCANIC ISLAND

A Volcanoes form when magma rises from deep within the Earth. Thousands of volcanoes form on the seafloor, and many emerge from the sea and form the base of islands.

B When a plate of the crust moves over a hot spot, a volcano begins to erupt and an island is born.





Frozen Flame

It is known as the land of ice and fire. Under Iceland's frozen surface there smolders a volcanic fire that at times breaks free and causes disasters. The island is located over a hot spot on the Central Atlantic Ridge. In this area the ocean bed is expanding, and large quantities of lava flow from vents, fissures, and craters.

ICELAND

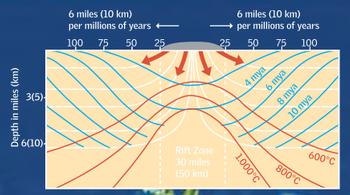
Latitude 64° 6′ N

Longitude -21° 54′ E

Surface Area	39,768 sq miles (103,000 sq km)
Population	293,577
Population density	1 per sq mile (2.8 per sq km)
Area of lakes	1,064 sq miles (2,757 sq km)
Glaciers	4,603 sq miles (11,922 sq km)

1/5

of all the lava that has emerged on the Earth's surface since 1500 has come from Iceland.

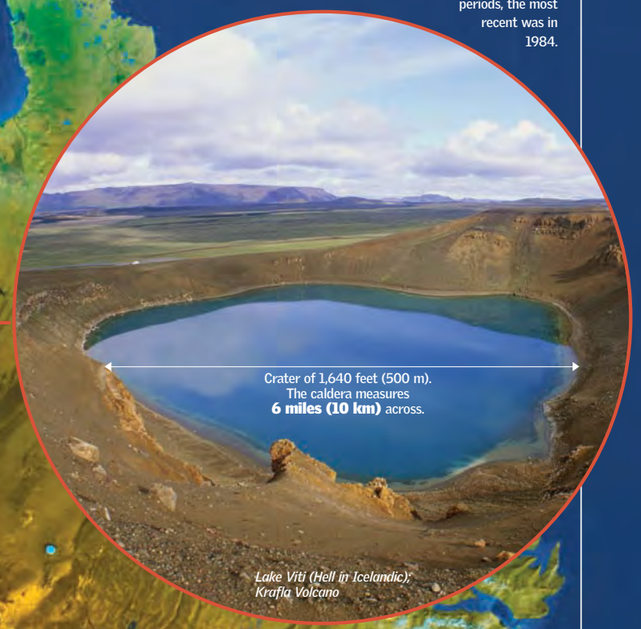


RIFT ZONE

If the rift zone that crosses the island from southwest to north were cut in two, different ages of the Earth would be revealed according to the segment being analyzed. For example, the rock 60 miles (100 km) from the rift is six million years old.

KAFLA VOLCANIC CRATER

This volcano has been very active throughout history. Of its 29 active periods, the most recent was in 1984.



Lake Viti (Hell in Icelandic); Krafla Volcano

ENERGY

The islanders use geothermal (steam) energy from volcanoes and geysers for heat, hot water, and electric energy.

REYKJAVIK

The capital of Iceland is the northernmost capital in the world.

SNAEFELLS
LYSUHOLL
PRESTAHNU
KERLINGAR
HOFSJOKUL
ASKJA
BARDARBUNGA
GLACIAL CAP OF VATNAJÖKULL
GRIMSVÖTN
REYKJAVIK
HENGILL
VATNAFJOL
REYKJANES
HEKLA
Its largest eruption was in 1104.
LAKI
The largest eruption of lava in history occurred in 1783: the ashes reached China.
TINDFJALL
KATLA
VESTMANNA
SURTSEY
THEISTARE
hot spot
KRAFLA
Lake Myvatn
FREMRINAM

Split Down the Middle

Part of Iceland rests on the North American Plate, which is drifting westward. The rest of Iceland is on the Eurasian Plate, drifting eastward. As tectonic forces pull on the plates, the island is slowly splitting in two and forming a fault. The edges of the two plates are marked by gorges and cliffs. Thus, the ocean bed is growing at the surface.

The magma that emerges at the surface comes from a series of central volcanoes separated by fissures.

Birth of an Island

On Nov. 15, 1963, an undersea volcanic eruption off the southern coast of Iceland gave rise to the island of Surtsey, the newest landmass on the planet. The eruption began with a large column of ash and smoke. Later, heat and pressure deep within the Earth pushed part of the Mid-Atlantic Ridge to the surface. The island kept growing for several months, and today it has a surface area of 1.0 square mile (2.6 sq km). The island was named after Surtur, a fire giant from Icelandic mythology.

1 The first eruptions were caused by the interaction of magma and water. The explosions were infrequent, and rocks were thrown only a few yards from the volcano.

2 Repeated eruptions expelled vapor and ash into the air, forming a column over 6 miles (10 km) high. The island was formed from volcanic blocks and masses of lava.

3 The entire process lasted three-and-a-half years. Over 0.25 cubic mile (1 cu km) of lava and ash was expelled, with only 9 percent of it appearing above sea level.

ERUPTION UNDER THE ICE

In 1996 a fissure opened up between Grimsvötn and Bardarbunga. The lava made a hole 590 feet (180 m) deep in the ice and released a column of ash and steam. The eruption lasted 13 days.

Study and Prevention

INCANDESCENT ROCK
A river of lava from Mt. Kilauea flows constantly, forming surface wrinkles that deform under the lightest step.

LATENT DANGER 46-47
LEARN MORE 48-49
PREPARATIONS FOR DISASTER 50-51
BURIED IN A DAY 52-55
ERUPTIONS THROUGH TIME 56-57

Large eruptions often give warning signs months in advance. These signs consist of any observable manifestation on the exterior of the Earth's crust. They may include emissions of steam, gases, or ash and rising temperatures in the lake that typically forms in the crater. This is why volcanic seismology is considered one of the most useful tools for protecting nearby towns. Several seismic recording stations are typically placed around the cone of an active volcano. Among other things, the readings scientists get give them a clear view of the varying depths of the volcano's tremors-extremely important data for estimating the probability of a major eruption. ●

Latent Danger

Some locations have a greater propensity for volcanic activity. Most of these areas are found where tectonic plates meet, whether they are approaching or moving away from each other. The largest concentration of volcanoes is found in a region of the Pacific known as the "Ring of Fire." Volcanoes are also found in the Mediterranean Sea, in Africa, and in the Atlantic Ocean.

Arctic Ocean

AVACHINSKY
Russia
This is a young, active cone inside an old caldera, on the Kamchatka peninsula.

NOVARUPTA
Alaska, U.S.
It is in the Valley of Ten Thousand Smokes.

MOUNT ST. HELENS
Washington, U.S.
It had an unexpected, violent eruption in 1980.

The Pacific "Ring of Fire"

Formed by the edges of the Pacific tectonic plate, where most of the world's volcanoes are found.

ASIA

FUJIYAMA
Japan
This sacred mountain is the country's largest volcano.

PINATUBO
Philippines
In 1991 it had the second most violent eruption of the 20th century.

50 Volcanoes

Indonesia has the highest concentration of volcanoes in the world. Java alone has 50 active volcanoes.

MAUNA LOA
Hawaii, U.S.
The largest active volcano on Earth is rooted in the ocean floor and takes up nearly half of the island.

KILAUEA
Hawaii, U.S.
The most active shield volcano, its lava flows have covered more than 40 square miles (100 sq km) since 1983.

KRAKATOA
Indonesia
Its 1883 eruption destroyed an entire island.

TAMBORA
Indonesia
In 1815 it produced 35 cubic miles (150 cu km) of ash. It was the largest recorded eruption in human history.

OCEANIA

Pacific Ocean

EAST EPI
Vanuatu
This is an undersea caldera with slow eruptions lasting for months.

Subduction

Most volcanoes in the western United States were formed by subduction of the Pacific Plate.

Indian Ocean

AUSTRALIAN PLATE

PACIFIC PLATE

The tallest

These are found in the middle of the Andes range, which forms part of the Pacific Ring of Fire. They were most active 10,000 years ago, and many are now extinct or dampened by fumarolic action.

The "top five" list changes when the volcanoes are measured from the base rather than from their altitude above sea level.

60

volcanoes erupt per year.

EURASIAN PLATE

Iceland

The western half of Iceland lies on the North American Plate, but the eastern half is on the Eurasian Plate.

ELDFELL
Iceland
During one eruption, it expelled 3,500 cubic feet (100 cu m) of lava per second.

ASIA

NORTH AMERICA

NORTH AMERICAN PLATE

VESUVIUS
Italy
Erupted twice during the 20th century.

EUROPE

The Antilles

The Lesser Antilles is a volcanically active region.

ETNA
Italy
10,990 feet (3,350 m) high; has been active for thousands of years.

CENTRAL AMERICA

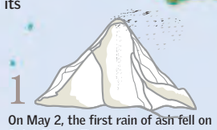
Atlantic Ocean

AFRICA

MT. PELÉE
Martinique
Its eruption completely destroyed the city of Saint-Pierre and its port in 1902.

Indian Ocean

1



On May 2, the first rain of ash fell on Saint-Pierre. The sky around the island was darkened for several days.

SOUTH AMERICA

NAZCAN PLATE

2

On May 5, near the summit, the caldera Etang Sec ruptured, releasing the water that it contained. A large lahar formed.

OJOS DEL SALADO
Chile/Argentina
The tallest volcano in the world, its last eruption was in 1956.

SOUTH AMERICAN PLATE

AFRICAN PLATE

3

On May 8, Saint-Pierre was destroyed by a burning cloud that devastated an area of 22 square miles (58 sq km), killing all 28,000 inhabitants.

ANTARCTIC PLATE

Danger

The most dangerous volcanoes are those located near densely populated areas, such as in Indonesia, the Philippines, Japan, Mexico, and Central America.

Increasing Knowledge

Volcanology is the scientific study of volcanoes. Volcanologists study eruptions from airplanes and satellites, and they film volcanic activity from far off. However, to study the inner workings of a volcano up close, they must scale near-vertical cliffs and face the dangers of lava, gas, and mudslides. Only then can they take samples and set up equipment to detect tremors and sounds.

SAMPLING OF VOLCANIC GASES
Gas and water vapor dissolved in magma provides the energy that powers eruptions. Visible emissions, such as sulfur and steam, are measured, as are invisible gases. Analyzing the gases' composition makes it possible to predict the beginning and end of an eruption.

GAS MASK

VACUUM TUBE

TITANIUM TUBE

Volcanologists Taking Gas Samples from a Fumarole on Lipari Island, Italy

Field Measurements

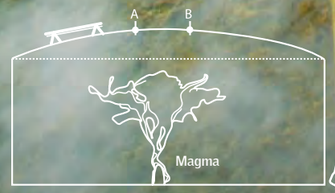
Monitoring a volcano includes gathering and analyzing samples and measuring various phenomena. Seismic movements, varying compositions of gases, deformations in the rock, and changes in electromagnetic fields induced by the movement of underground magma can all provide clues to predict volcanic activity.

FUMAROLE

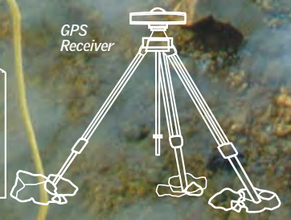
GAS ESCAPING FROM CRACK

Thermopar

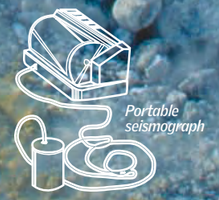
LAVA TEMPERATURE
is measured with a thermometer called a Thermopar; glass thermometers would melt from the heat. Temperatures of water and of nearby rocks are other variables to take into account.



TILTOMETERS
These are placed on the slopes of a volcano to record soil changes that precede an eruption. Points are determined (A-B) to monitor how pressure from the magma deforms the surface between them.



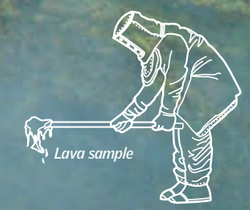
GLOBAL POSITIONING SYSTEM (GPS)
Movements in the magma cause hundreds of cracks in the cone. A GPS system records images continuously and analyzes the deformation over a period of time.



TEMBLORS OR EARTHQUAKES
Portable seismographs are used to detect movements in the ground within 6 miles (10 km) of the volcano that is being studied. These tremors can give clues about the movements of the magma.

THE SIZE OF THE CRATER
The widening of the crater caused by volcanic activity and the growth of the solid lava domes are measured. This growth implies certain risks for the proximity of an eruption.

HYDROLOGICAL MONITORING
Mudslides, or lahars, can bury large areas. Monitoring the volume of water in the area makes it possible to alert and evacuate the population when the amount of water passes critical points.



LAVA COLLECTION
The study of lava can determine its mineral composition and its origin. Lava deposits are also analyzed because the history of a volcano's eruptions can give clues about a future eruption.

Preparations for Disaster

Volcanic eruptions are dangerous to surrounding populations for two basic reasons. One danger is posed by the volcanic material that flows down the sides of the volcano (lava flows and mudslides), and the other danger is from the volcano's pyroclastic material, especially ash. Ash fallout can bury entire cities. Experts have developed an effective series of prevention and safety measures for people living in volcanic areas. These measures greatly reduce the highest risks.

Before an Eruption

It is best to get informed about safety measures, evacuation routes, safe areas, and alarm systems before a volcanic eruption. Other safety measures include stocking up on nonperishable food, obtaining gas masks and potable water, and checking the load-bearing capacity of roofs.

Do not carry more than **44 pounds (20 kg)** OF PROVISIONS.

Evacuation of Nearby Areas

In the immediate area (within 12 miles [20 km]) of the volcano, evacuation is the only possible safety measure. Returning home will be possible only when permission is given. Keep in mind that it takes a long time for life to return to normal after an evacuation.

MEDICAL PRECAUTIONS
Keep a first-aid kit and essential medications on hand, and keep vaccinations up to date.

SHUT OFF UTILITIES
Before leaving a house, shut off the electricity, gas, and water. Tape doors and windows shut.

PROVISIONS
Water and food are indispensable, especially if you evacuate the area on your own.

CIVIL DEFENSE
Follow all recommendations, be alert to official information, and do not spread rumors.

RIVERS AND STREAMS
Large volumes of water pose a threat of mudslides. Avoid these areas.

MAIN ROUTES
These usually cross low-lying areas. They can be a potential path for flows of lava or mud.

BRIDGES
When possible, do not use for your evacuation route because they might collapse.

HIGHER ELEVATIONS
These are the preferred sites for evacuations from volcanic eruptions. High ground is safe from lahars and lava flows, and if there is shelter there, it is also safe from rains of ash.

12 miles (20 km)

Areas of Falling Ash

Most of the population lives outside the volcano's range, but ash from an eruption can become highly volatile and fall over wide areas. Wind can carry ash to other areas, so the best preventive efforts are focused on warning people about what to do in case of falling ash.

AT HOME
It is best to stay indoors during an ashfall. One of the main precautions is to provide for potable drinking water, because the usual water supply will be interrupted because of pollution risks, especially if the water supply comes from lakes or rivers in the area.

AVOID DRIVING
If you must drive, do so slowly and turn on your headlights. It is best to leave the car parked in an enclosed space or under cover.

STAY CALM
To breathe, cover your face with a handkerchief soaked in water and vinegar.

DOORS AND WINDOWS
It is best to always leave doors and windows shut tightly, as airtight as possible, for as long as the ashfall continues.

DO NOT WASH WITH WATER
After the ashfall, washing with water will form a sticky and heavy paste that will be very hard to remove.

WATER TANK
Roof-mounted water tanks should be disconnected and covered until the roof has been cleared of ashes.

ASH ON THE ROOF
Ash should be removed immediately (before it rains) so the roof does not collapse.

AIR CONDITIONING
Air conditioners and large clothes dryers should not be used during an eruption.

MASKS
Use masks and special ash-protective clothing when outdoors.

INFORMATION
Listen to the radio at all times.

CHILDREN
If children are at school, do not go to pick them up: they will be safe there.

LAHARS AND PYROCLASTIC FLOWS
Lahars (mudflows) can form from rainwater or melting snow. Volcanic danger zones often have strategies to divert rivers and reduce the volume of water in dams and reservoirs.

12 miles (20 km)
Considered to be the critical distance from a volcano in emergency relief efforts.

WIND AND RAIN
Wind is a risk factor that spreads volatile ash over a large area so that settlements at a distance greater than 60 miles (100 km) can be affected. The greatest danger posed by falling ash is that it can mix with rain falling on the roofs of houses and form a heavy mass that will collapse the buildings.

60 miles (100 km)

ALTERNATIVE ROUTES
Roads running through higher elevations are preferred because they cannot be reached by lava and mudflows.

Buried in One Day

At noon on Aug. 24, AD 79, Mount Vesuvius erupted near the coast of Naples Bay. The Roman cities of Pompeii and Herculaneum were completely buried in ashes and pyroclasts, in what would become one of the worst natural tragedies of ancient times. Many details from that day have reached us thanks to the narrative of Pliny the Younger. His well-known description of the eruption column as "shaped like a pine" caused this type of eruption to be named after him: a "Plinian eruption."

10 A.M.

1 AN ALMOST NORMAL DAY
Tremors and earthquakes had been felt in the city for four days. Hanging lamps swayed, furniture moved, and some door frames had even cracked. Because these things happened about once a year without any consequences, the inhabitants of Pompeii continued with their normal lives. The public forum was filled with people. The festivities of Isis were celebrated in the temple of Apollo.

POMPEII'S FORUM
This was the political, religious, and commercial heart of the city. Every day the forum was alive with Pompeii's citizens, as it was on August 24.

1 P.M.

2 THE ERUPTION.
Suddenly Vesuvius spewed out a huge column of smoke, lava, and ash that formed a pyroclastic flow moving toward Pompeii. People ran in all directions seeking refuge in houses. The roughness of the sea made escape by water impossible.

RAIN OF STONES
Moments after the eruption, incandescent pumice stones fell from the sky.

RICHES
Several precious objects such as this gold bracelet have been unearthed.

23 feet (7 m)
The maximum depth of the ashes.

The Violent Awakening

Mount Vesuvius had been inactive for more than 800 years, until the pressure that had accumulated inside produced its explosion in the year 79. Most of the deaths during this tragedy were originally blamed on the ash that buried parts of the neighboring settlements (Herculaneum and Stabiae, as well as Pompeii). Now, though, the eruption is believed to have produced the typical "burning clouds" of a Plinian eruption: Flames of incandescent ash and gases were expelled at high speeds by the eruptive pressure. Suspended moist particles charged the air with electricity, causing an intense electric storm, whose flashes of lightning would have been the only source of light under the ashfall. Since then Vesuvius has had a dozen other important eruptions. The worst killed 4,000 people in 1631. The first volcanology observatory in the world was installed at Vesuvius in 1841.

POMPEII, ITALY
Latitude 40° 49′ N
Longitude 14° 26′ E

Distance from Vesuvius	6 miles (10 km)
Population in the year AD 79	20,000 people
Current population	27,000 people
Ash dispersion (79)	60 miles (100 km) (SE)
Last Eruption of Vesuvius	1944

9 P.M.

3 A TWO-DAY NIGHT
The tongues of lava from the volcano were seen better at night. The next morning the Sun's light could not be seen through the ash cloud. Pliny's narrative mentions a constant rain of pyroclasts, continuing on the following morning, and emissions of sulfuric gases that killed many people. Many sought shelter on the beaches. Only on August 26 did the ashfall begin to disperse.

SEQUENCE OF THE ERUPTION

For more than 20 hours (the time the eruption lasted), the ash column rose and then fell on the surrounding area.

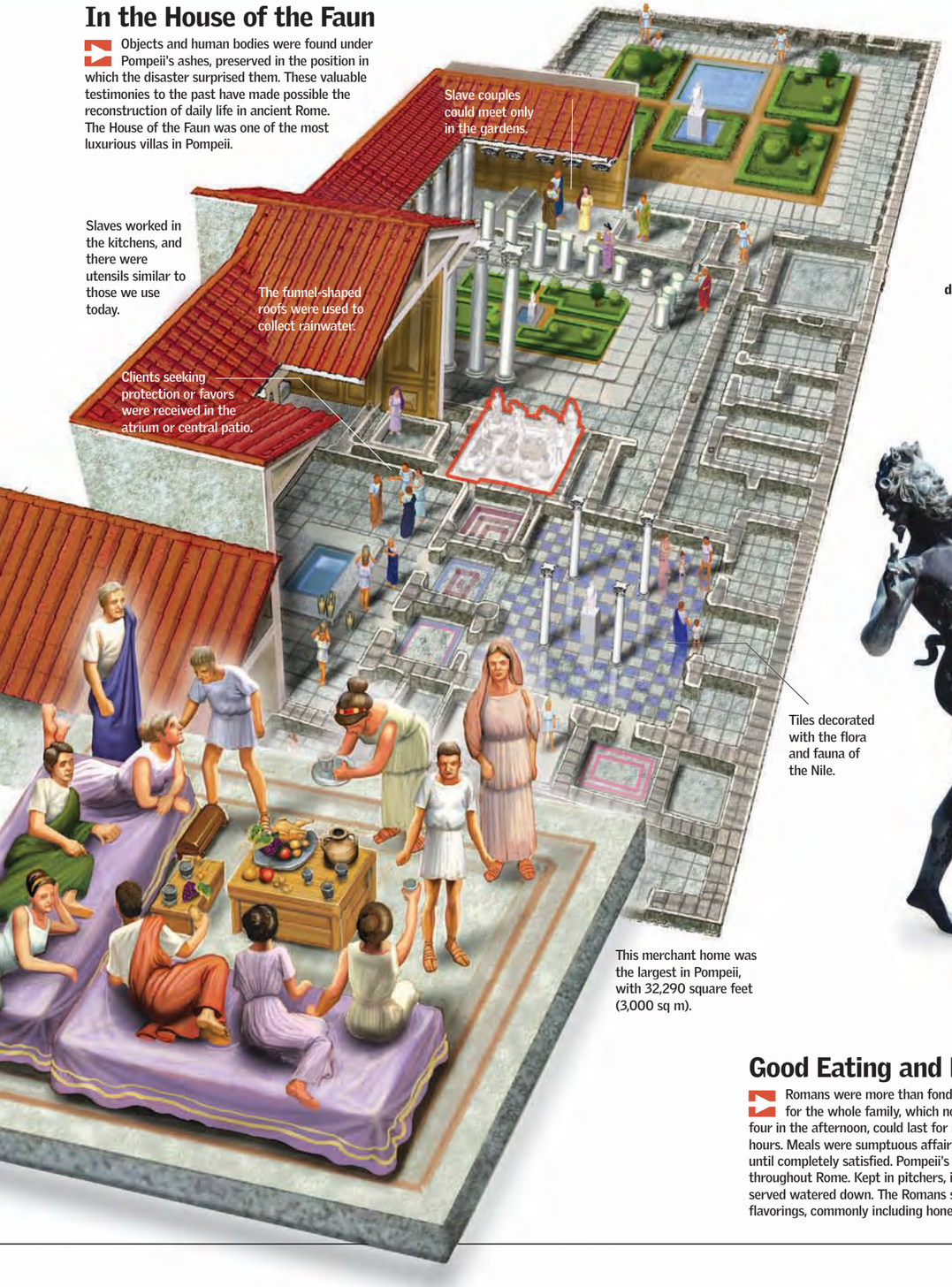
1 After the first explosion, the column of smoke began its vertical climb. The wind blew it toward the southeast.

2 The cloud spread nearly 60 miles (100 km) from side to side, and ash fell on the city for a whole day.

3 By 7:30 A.M. on August 25, the pyroclastic flows reached Pompeii. These flows are estimated to have reached temperatures of 1,022° F (550° C).

In the House of the Faun

Objects and human bodies were found under Pompeii's ashes, preserved in the position in which the disaster surprised them. These valuable testimonies to the past have made possible the reconstruction of daily life in ancient Rome. The House of the Faun was one of the most luxurious villas in Pompeii.



This merchant home was the largest in Pompeii, with 32,290 square feet (3,000 sq m).

BRONZE FAUN
The name given to the house is from this statue found in the villa's atrium. The faun was considered a wild deity, with the ability to predict the future.

Good Eating and Drinking

Romans were more than fond of feasts. A dinner for the whole family, which normally began at four in the afternoon, could last for more than four hours. Meals were sumptuous affairs, and no one left until completely satisfied. Pompeii's wine was famous throughout Rome. Kept in pitchers, it was always served watered down. The Romans sometimes added flavorings, commonly including honey and pepper.

As in That Moment

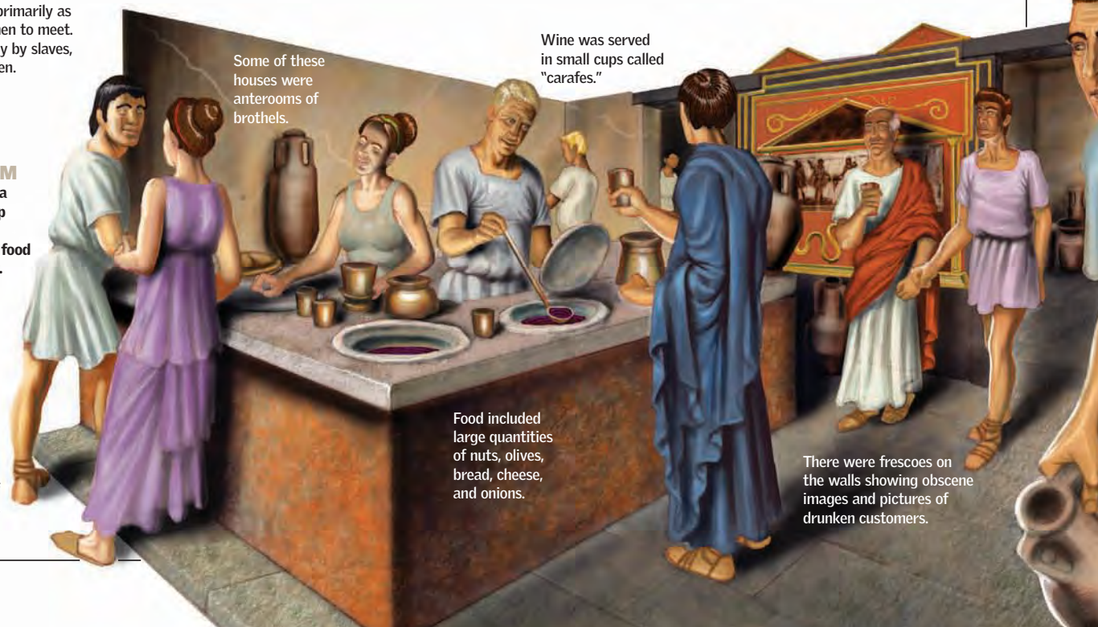
In 1709, some of Pompeii's artifacts were found buried under volcanic ash, and that started a treasure hunt. It was not until 1864, though, that reconstruction and conservation of materials began with the work of Giuseppe Fiorelli. The exhibits that are the most fascinating to people who visit Pompeii's ruins today (about two million people every year) are his reconstructions of the bodies.

In a Pompeii Bar

There were several types of food and drink establishments in Pompeii, from food vendors in the streets to luxury services. These food places served many different social purposes but acted primarily as places for businessmen to meet. They were run mostly by slaves, men as well as women.

THE THERMOPOLIUM
The typical bar had a long marble tabletop with embedded containers in which food could be kept warm.

200
was the approximate number of places of this type in the city.



1 THE CATASTROPHE
Several corpses were covered by volcanic ash, which had accumulated in layers and later hardened. The bodies had decomposed, but their forms were molded in the volcanic rock.

2 RECONSTRUCTION
The work of Fiorelli was to fill these natural "tombs" (ash molds) with plaster. When the plaster hardened, the surrounding layers of ash were removed, leaving the outlines or molds of the bodies.

3 THE FORM, UNTOUCHED
Making plaster casts allowed precise reconstructions of the people's postures at the time of the disaster, and we have been able to learn details such as the hairstyles and dress of these people. Animal forms and other organic objects have also been reconstructed. Today the use of resins and silicones makes it possible to obtain even greater detail.

Historic Eruptions

The lava falls and flows, sweeping away everything in its path. This happens in a slow, uninterrupted way, and the lava destroys entire cities, towns, and forests and claims thousands of human lives. One of the most famous examples was the eruption of Mount Vesuvius in AD 79, which wiped out two cities and two cultures, those of Pompeii and Herculaneum. In the 20th century, the eruption of Mount Pelée destroyed the city of Saint-Pierre in Martinique in a few minutes and instantly killed almost its entire population. Volcanic activity also seems to be closely related to changes in climate.

AD 79

MOUNT VESUVIUS
Naples, Italy

Volume of ejected ash in cubic feet (cu m)	**141,000 (4,000)**
Victims	**2,200**
Characteristics	**Active**

The cities of Pompeii and Herculaneum were destroyed in AD 79 when Mount Vesuvius erupted. Until that day, it was not known that the mountain was a volcano because it had been inactive for over 300 years. This was one of the first eruptions to be recorded: Pliny the Younger stated in one of his manuscripts that he had seen how the mountain exploded. He described the gas and ash cloud rising above Vesuvius and how thick, hot lava fell. Many people died because they inhaled the poisonous gases.

Volcanoes and Climate

There is a strongly supported theory that relates climate changes to volcanic eruptions. The idea of linking the two phenomena is based on the fact that explosive eruptions spew huge amounts of gases and fine particles high into the stratosphere, where they spread around the Earth and remain for years. The volcanic material blocks a portion of solar radiation, reducing air temperatures around the world. Perhaps the most notable cold period related to volcanic activity was the one that followed the eruption of Tambora in 1815. Some areas of North America and Europe had an especially harsh winter.

KALAPANA. After the Kilauea volcano (Hawaii) erupted in 1991, a lava flow advanced on the city, covering everything in its path.

1783

LAKI VOLCANO
Iceland

Volume of ejected ash in cubic feet (cu m)	**490 billion (14 billion)**
Victims	**10,000**
Characteristics	**Very active**

In spite of the fact that the eruptions are related to conic forms, most of the volcanic material comes out through fractures in the crust, called "fissures." The fissure eruptions of Laki were the greatest in Iceland; they created more than 20 vents in a distance of 15 miles (25 km). The gases ruined grasslands and killed livestock. The subsequent famine took the lives of 10,000 people.

1815

TAMBORA VOLCANO
Indonesia

Volume of ejected ash in cubic feet (cu m)	**100 billion (3 billion)**
Victims	**10,000**
Characteristics	**Stratovolcano**

After giving off fumes for seven months, Tambora erupted, and the ensuing catastrophe was felt around the globe. The ash cloud expanded to more than 370 miles (600 km) away from the epicenter of the eruption, and it was so thick that it hid the Sun for two days. The ashfall covered an area of 193,051 square miles (500,000 sq km). It is considered to be the most destructive volcanic explosion that ever took place. More than 10,000 people died during the eruption, and 82,000 died of illness and starvation after the eruption.

1883

KRAKATOA VOLCANO
Java, Indonesia

Volume of ejected ash in cubic feet (cu m)	**670 billion (19 billion)**
Victims	**36,000**
Characteristics	**Active**

Even though Krakatoa began to announce its forthcoming eruption with clouds of vapor and smoke, these signs, instead of preventing a disaster, became a tourist attraction. When the explosion took place, it destroyed two thirds of the island. Stones shot from the volcano reached a height of 34 miles (55 km)-beyond the stratosphere. A crater 4 miles (6.4 km) in diameter opened a chasm 820 feet (250 m) deep. Land and islands were swept bare.

1902

MOUNT PELÉE
Martinique, Antilles

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**30,000**
Characteristics	**Stratovolcano**

A burning cloud and a thick mass of ash and hot lava were shot from this small volcano that completely destroyed the port city of Saint-Pierre. Most striking is the fact that this destruction took place in only a few minutes. The energy released was so great that trees were uprooted. Almost the entire population died, and only three people survived, one of them because he was trapped in the city jail.

1944

MOUNT VESUVIUS
Naples, Italy

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**2,000**
Characteristics	**End of a cycle**

With this last activity, the Vesuvius volcano ended the cycle of eruptions it began in 1631. This explosion, along with the previous one in 1906, caused severe material damage. The eruptions were responsible for more than 2,000 deaths from avalanches and lava bombs. Additionally, the 1944 eruption took place during World War II and caused as much damage as the eruption at the beginning of the 20th century had, because it flooded Somma, Atrio de Cevallo, Massa, and San Sebastiano.

1973

ELDFELL VOLCANO
Heimaey Islands, Iceland

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**0**
Characteristics	**656 feet (200 m)**

The lava advanced, and it appeared that it would take everything in its path. Volcanologists decided that Heimaey Island, south of Iceland, should be evacuated. But a physics professor proposed watering the lava with seawater to solidify or harden it. Forty-seven pumps were used, and, after three months and 6.5 million tons (6 million metric tons) of water, the lava was stopped, and the port was saved. The eruption began on January 23 and ended on June 28.

1980

MOUNT ST. HELENS
State of Washington, U.S.

Volume of ejected ash in cubic feet (cu m)	**35 billion (1 billion)**
Victims	**57**
Characteristics	**Active**

Also known as the Mount Fuji of the American continent. During the 1980 explosion, 1,315 feet (401 m) of the mountain's top gave way through a fault on its side. A few minutes after the volcano began its eruption, rivers of lava flowed down its sides, carrying away the trees, houses, and bridges in their path. The eruption destroyed whole forests, and the volcanic debris devastated entire communities.

1982

EL CHICHÓN VOLCANO
Mexico

Volume of ejected ash in cubic feet (cu m)	**No figures available**
Victims	**2,000**
Characteristics	**Active**

On Sunday, March 28, after 100 years of inactivity, this volcano became active again and unleashed an eruption on April 4. The eruption caused the deaths of about 2,000 people who lived in the surrounding area, and it destroyed nine settlements. It was the worst volcanic disaster in Mexico's history.

Earthquakes

LOMA PRIETA
On Oct. 18, 1989, an earthquake measuring 7.0 on the Richter scale, with its epicenter in Loma Prieta, 52 miles (85 km) south of San Francisco, caused great damage, including the collapse of a section of the Bay Bridge.

DEEP RUPTURE 60-61
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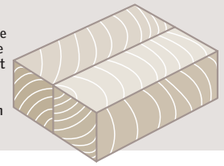
Earthquakes shake the ground in all directions, even though the effects of a quake depend on the magnitude, depth, and distance from its point of origin. Often the waves are so strong that the Earth buckles, causing the collapse of houses and buildings, as happened in Loma Prieta. In mountainous regions earthquakes can be followed by landslides and mudslides, whereas in the oceans, tsunamis may form; these walls of water strike the coast with enough force to destroy whole cities, as occurred in Indonesia in December 2004. Thailand recorded the highest number of tourist deaths, and 80 percent of tourist areas were destroyed. ●

Deep Rupture

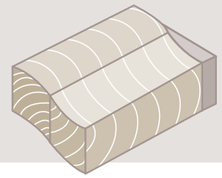
Earthquakes take place because tectonic plates are in constant motion, and therefore they collide with, slide past, and in some cases even slip on top of each other. The Earth's crust does not give outward signs of all the movement within it. Rather energy builds up from these movements within its rocks until the tension is more than the rock can bear. At this point the energy is released at the weakest parts of the crust. This causes the ground to move suddenly, unleashing an earthquake.

ORIGIN OF AN EARTHQUAKE

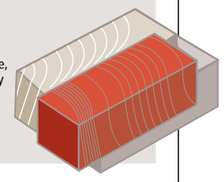
1
Tension Is Generated
The plates move in opposite directions, sliding along the fault line. At a certain point along the fault, they catch on each other. Tension begins to increase between the plates.



2
Tension Versus Resistance
Because the force of displacement is still active even when the plates are not moving, the tension grows. Rock layers near the boundary are distorted and crack.



3
Earthquake
When the rock's resistance is overcome, it breaks and suddenly shifts, causing an earthquake typical of a transform-fault boundary.



1 FORESHOCK
Small tremor that can anticipate an earthquake by days or even years. It could be strong enough to move a parked car.

2 AFTERSHOCK
New seismic movement that can take place after an earthquake. At times it can be even more destructive than the earthquake itself.

3 EARTHQUAKE
The main movement or tremor lasts a few seconds, after which some alterations become visible in the terrain near the epicenter.

EARTHQUAKES PER YEAR

MAGNITUDE	QUANTITY
8 or Greater	1
7 to 7.9	18
6 to 6.9	120
5 to 5.9	800
4 to 4.9	6,200
3 to 3.9	49,000

30 Seconds
The time lapse between each tremor of the Earth's crust

EPICENTER
Point on the Earth's surface located directly above the focus.

HYPOCENTER OR FOCUS
Point of rupture, where the disturbance originates. Can be up to 435 miles (700 km) below the surface.

SOUTHERN ALPS

ALPINE FAULT

SOUTH ISLAND

7.05

7.65 Richter

6.10

LAKE TEKAPO

Riverbeds follow a curved path because of movement along the fault line.

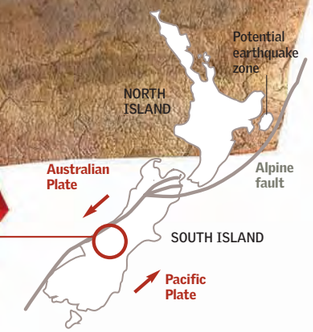
PLAIN

FAULT PLANE
Usually curves rather than following a straight line. This irregularity causes the tectonic plates to collide, which leads to earthquakes as the plates move.

SEISMIC WAVES
transmit the force of the earthquake over great distances in a characteristic back-and-forth movement. Their intensity decreases with distance.

FOLDS
These result from tension that accumulates between tectonic plates. Earthquakes release part of the tension energy generated by orogenic folds.

15 miles (25 km)
Average depth of the Earth's crust below the island.



NEW ZEALAND
Latitude 42° S
Longitude 174° E

Surface area	103,737 square miles (268,680 sq km)
Population	4,137,000
Population density	35 people per square mile (13.63 people per sq km)
Earthquakes per year (>4.0)	60-100
Total earthquakes per year	14,000

ALPINE FAULT IN NEW ZEALAND
As seen in the cross-section, South Island is divided by a large fault that changes the direction of subduction, depending on the area. To the north the Pacific Plate is sinking under the Indo-Australian Plate at an average rate of 1.7 inches (4.4 cm) per year. To the south, the Indo-Australian Plate is sinking 1.4 inches (3.8 cm) per year under the Pacific Plate.

FUTURE DEFORMATION OF THE ISLAND

2 million years

4 million years

To the west there is a plain that has traveled nearly 310 miles (500 km) to the north in the past 20 million years.

Elastic Waves

Seismic energy is a wave phenomenon, similar to the effect of a stone dropped into a pool of water. Seismic waves radiate out in all directions from the earthquake's hypocenter, or focus. The waves travel faster through hard rock and more slowly through loose sediment and through water. The forces produced by these waves can be broken down into simpler wave types to study their effects.

Focus
Vibrations travel outward from the focus, shaking the rock.

2.2 miles per second (3.6 km/s)
S waves are 1.7 times as slow as P waves.

They travel only through solids. They cause splitting motions that do not affect liquids. Their direction of travel is perpendicular to the direction of travel.

Different Types of Waves

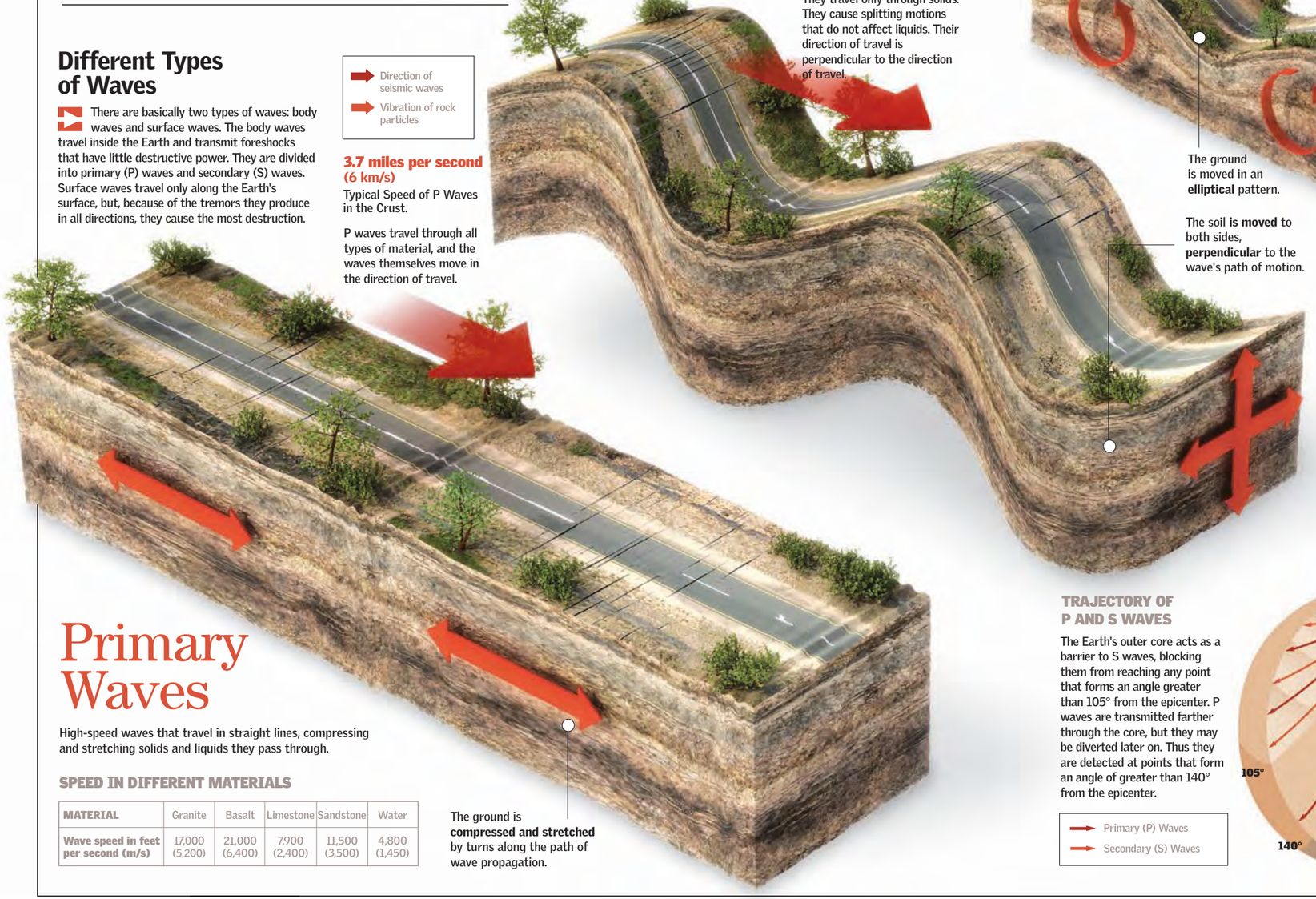
There are basically two types of waves: body waves and surface waves. The body waves travel inside the Earth and transmit foreshocks that have little destructive power. They are divided into primary (P) waves and secondary (S) waves. Surface waves travel only along the Earth's surface, but, because of the tremors they produce in all directions, they cause the most destruction.

Direction of seismic waves

Vibration of rock particles

3.7 miles per second (6 km/s)
Typical Speed of P Waves in the Crust.

P waves travel through all types of material, and the waves themselves move in the direction of travel.



Primary Waves

High-speed waves that travel in straight lines, compressing and stretching solids and liquids they pass through.

SPEED IN DIFFERENT MATERIALS

MATERIAL	Granite	Basalt	Limestone	Sandstone	Water
Wave speed in feet per second (m/s)	17,000 (5,200)	21,000 (6,400)	7,900 (2,400)	11,500 (3,500)	4,800 (1,450)

The ground is **compressed and stretched** by turns along the path of wave propagation.

Surface Waves

appear on the surface after the P and S waves reach the epicenter. Having a lower frequency, surface waves have a greater effect on solids, which makes them more destructive.

1.9 miles per second (3.2 km/s)
Speed of surface waves in the same medium.

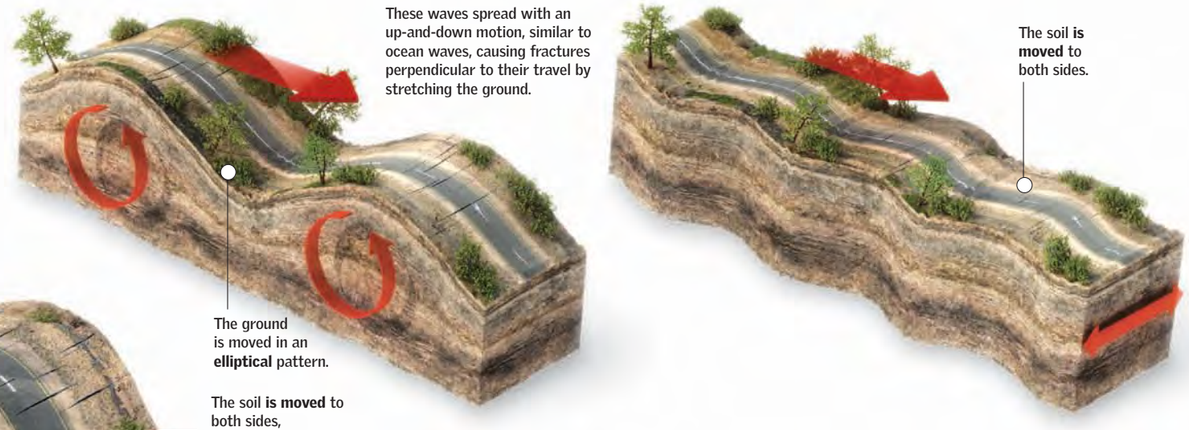
These waves travel only along the surface, at 90 percent of the speed of S waves.

LOVE WAVES

These move like horizontal S waves, trapped at the surface, but they are somewhat slower and make cuts parallel to their direction.

RAYLEIGH WAVES

These waves spread with an up-and-down motion, similar to ocean waves, causing fractures perpendicular to their travel by stretching the ground.



Secondary Waves

Body waves that shake the rock up and down and side to side as they move.

SPEED IN DIFFERENT MATERIALS

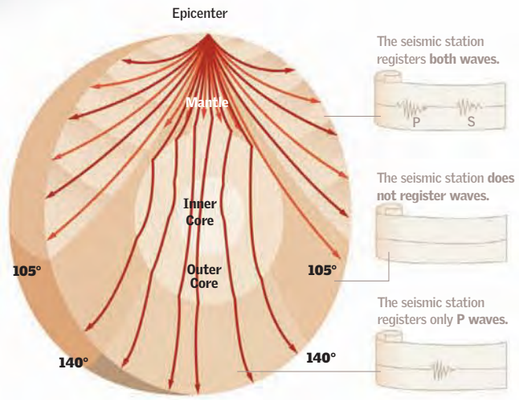
MATERIAL	Granite	Basalt	Limestone	Sandstone
Wave speed in feet per second (m/s)	9,800 (3,000)	1,500 (3,200)	4,430 (1,350)	7,050 (2,150)

TRAJECTORY OF P AND S WAVES

The Earth's outer core acts as a barrier to S waves, blocking them from reaching any point that forms an angle greater than 105° from the epicenter. P waves are transmitted farther through the core, but they may be diverted later on. Thus they are detected at points that form an angle of greater than 140° from the epicenter.

Primary (P) Waves

Secondary (S) Waves



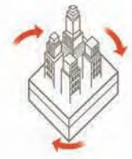
Types of Earthquakes

Although earthquakes generally cause all types of waves, some kinds of waves may predominate. This fact leads to a classification that depends on whether vertical or horizontal vibration causes the most movement. The depth of the epicenter can also affect its destructiveness.

BASED ON TYPE OF MOVEMENT

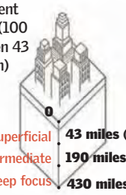
Trepidatory
Located near the epicenter, where the vertical component of the movement is greater than the horizontal.

Oscillatory
When a wave reaches soft soil, the horizontal movement is amplified, and the movement is said to be oscillating.



BASED ON FOCUS DEPTH

Earthquakes originate at points between 3 and 430 miles (5 and 700 km) underground. Ninety percent originate in the first 62 miles (100 km). Those originating between 43 and 190 miles (70 and 300 km) are considered intermediate. Superficial earthquakes (often of higher magnitude) occur above that level, and deep-focus earthquakes occur below it.



OAKLAND, CALIFORNIA

Latitude 37° 46′ N

Longitude 122° 13′ W

Surface area of state	**156,100 square miles (404,298 sq km)**
Range of Damages	**68 miles (110 km)**
State population	**36,132,147**
Earthquakes per year (>4.0)	**15-20**
Earthquake victims	**63**
Magnitude on Richter scale	**7.1**

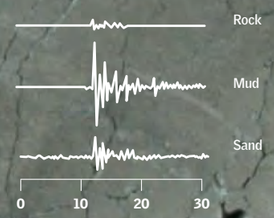
Bursts of tension

Seismic energy can even be compared to the power of nuclear bombs. In addition, the interaction between seismic waves and soil materials also causes a series of physical phenomena that can intensify its destructive capacity. An example of such an effect occurred when a section of an interstate highway plummeted to the ground during the 1989 earthquake in Loma Prieta, California.

THE HIGHWAY

Each soil type responds differently to an earthquake. The figure shows how the same quake can produce waves of different strengths in different soils of different composition. The 0.86-mile (1.4-km) collapsed section of Interstate 880 was built on the mud of San Francisco Bay.

SEISMOGRAPH READOUT

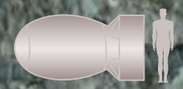


FACTORS THAT DETERMINE THE EFFECTS OF AN EARTHQUAKE

INTRINSIC
- Magnitude
- Type of wave
- Depth

GEOLOGIC
- Distance
- Wave direction
- Topography
- Groundwater saturation

SOCIAL
- Quality of construction
- Preparedness of the population
- Time of day



4 = 1,000 tons

Magnitude Energy released by TNT

The energy released by an earthquake of magnitude 4 on the Richter scale is equal to the energy released by a low-power atomic bomb.

7 = 32 million tons

Magnitude Energy released by TNT

The energy released by an earthquake of magnitude 7 on the Richter scale, such as the 1995 earthquake in Hyogo-Ken Nanbu, Japan, is equal to the energy released by a high-powered thermonuclear bomb (32 megatons).

12 = 160 quadrillion tons

Magnitude Energy released by TNT

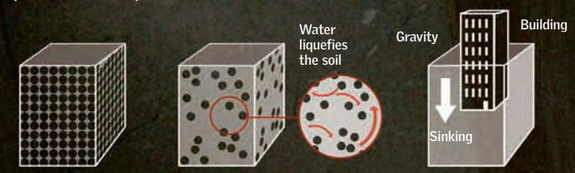
The energy released by a hypothetical earthquake of magnitude 12 on the Richter scale (the greatest known earthquake was 9.5) would be equal to the energy released if the Earth were to split in half.

DIRECT AND INDIRECT EFFECTS

Direct effects are felt in the fault zone and are rarely seen at the surface. Indirect effects stem from the spread of seismic waves. In the Kobe earthquake, the fault caused a fissure in the island of Awaji up to 10 feet (3 m) deep. The indirect effects had to do with liquefaction.

Liquefaction

Seismic tremors apply a force to muddy or water-saturated soils, filling the empty spaces between grains of sand. Solid particles become suspended in the liquid, the soil loses its load-bearing capacity, and buildings sink as if the ground were quicksand. That displaces some of the water, which rises to the surface.



1 The soil is compact, even though it contains water.

2 During the earthquake, the water causes the solid particles to shake.

3 Solid structures sink, and water rises.

Measuring an Earthquake

Earthquakes can be measured in terms of force, duration, and location. Many scientific instruments and comparative scales have been developed to take these measurements. Seismographs measure all three parameters. The Richter scale describes the force or intensity of an earthquake. Naturally, the destruction caused by earthquakes can be measured in many other ways: numbers of people left injured, dead, or homeless, damage and reconstruction costs, government and business expenditures, insurance costs, school days lost, and in many more ways.

CHARLES RICHTER

American seismologist (1900-85) who developed the scale of magnitude that bears his name.

GIUSEPPE MERCALLI

Italian volcanologist (1850-1914) who developed the first scale for measuring the intensity of an earthquake.

USE OF SCALES WORLDWIDE

Richter and Mercalli · EMS

EMS 98 SCALE

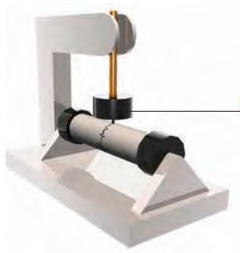
In use since 1998 throughout the European Union and other countries that use the protocol, including those of northern Africa. This scale describes the intensity of earthquakes in European contexts, where the most modern construction may be found side by side with ancient buildings. Earthquakes there can have widely varying effects. The scale has 12 points that combine magnitude readings with levels of destruction.

Intensity

Concept of the destruction caused by an earthquake.

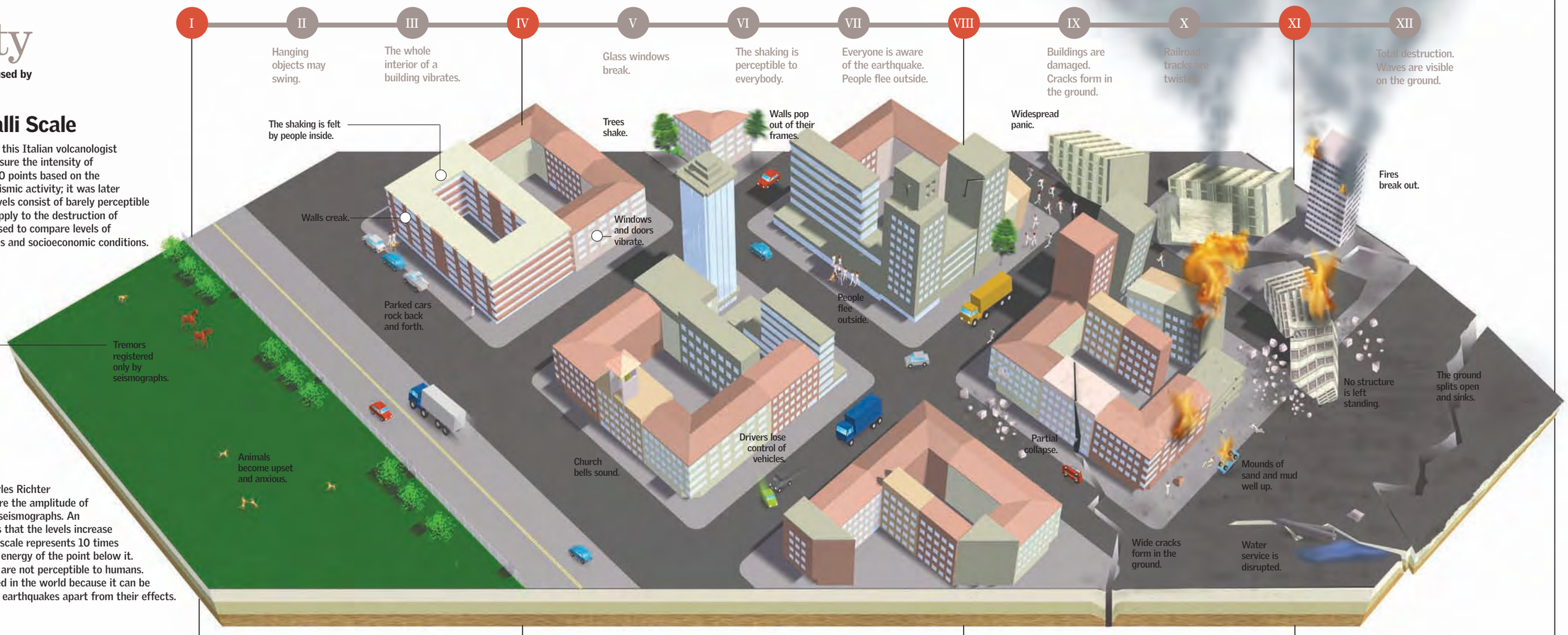
Modified Mercalli Scale

Between 1883 and 1902, this Italian volcanologist developed a scale to measure the intensity of earthquakes. It originally had 10 points based on the observation of the effects of seismic activity; it was later modified to 12. The first few levels consist of barely perceptible sensations. The highest levels apply to the destruction of buildings. This scale is widely used to compare levels of damage among different regions and socioeconomic conditions.



Richter Scale

In 1935, seismologist Charles Richter designed a scale to measure the amplitude of the largest waves registered by seismographs. An important feature of this scale is that the levels increase exponentially. Each point on the scale represents 10 times the movement and 30 times the energy of the point below it. Temblors of magnitude 2 or less are not perceptible to humans. This scale is the most widely used in the world because it can be used to compare the strength of earthquakes apart from their effects.



Magnitude

The energy released in a seismic event.

2	2.5	3.5	4.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Registered only by seismographs.	Very few people feel the tremor.	The tremor is felt. Only minor damages.	Most people perceive the quake.	Some buildings are lightly damaged.	May cause severe damage.	Unstable buildings are destroyed.	May cause heavy damage in populated areas.	Major earthquake. Causes extensive damage.	Considered a great earthquake.	Causes very extensive damage.	Very great earthquake. Total destruction.

Violent Seas

A large earthquake or volcanic eruption can cause a tsunami, which means "wave in the harbor" in Japanese. Tsunamis travel very fast, up to 500 miles per hour (800 km/h). On reaching shallow water, they decrease in speed but increase in height. A tsunami can become a wall of water more than 33 feet (10 m) high on approaching the shore. The height depends partly on the shape of the beach and the depth of coastal waters. If the wave reaches dry land, it can inundate vast areas and cause considerable damage. A 1960 earthquake off the coast of Chile caused a tsunami that swept away communities along 500 miles (800 km) of the coast of South America. Twenty-two hours later the waves reached the coast of Japan, where they damaged coastal towns.

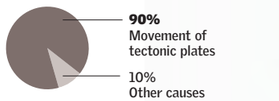
津 波

The word tsunami comes from Japanese

TSU Harbor **NAMI** Wave

How It Happens

A tremor that generates vibrations on the ocean water's surface can be caused by seismic movement on the seafloor. Most of the time the tremor is caused by the upward or downward movement of a block of oceanic crust that moves a mass of ocean water. A volcanic eruption, meteorite impact, or nuclear explosion can also cause a tsunami.



RISING PLATE

Water level rises

Water level drops

SINKING PLATE

The displaced water tends to level out, generating the force that causes waves.

7.5

Only earthquakes above this magnitude on the Richter scale can produce a tsunami strong enough to cause damage.

1 THE EARTHQUAKE
A movement of the ocean floor displaces an enormous mass of water upward.

2 THE WAVES ARE FORMED
As this mass of water drops, the water begins to vibrate. The waves, however, are barely 1.5 feet (0.5 m) high, and a boat may cross over them without the crew even noticing.

3 THE WAVES ADVANCE
Waves may travel thousands of miles without weakening. As the sea becomes shallower near the coast, the waves become closer together, but they grow higher.

4 TSUNAMI
On reaching the coast, the waves find their path blocked. The coast, like a ramp, diverts all the force of the waves upward.

Displacement of the plate.

CREST

TROUGH

CREST

LENGTH OF THE WAVE
From 62 to 430 miles (100 to 700 km) on the open sea, measured from crest to crest.

Float
System of glass spheres.

Chain

Detection device.
Located at a depth of 16,000 feet (5,000 m).

OCEAN FLOOR

518 miles/hour
(835 km/h)
Speed of the tsunami

18,000 feet
(5,500 m)

210 miles/hour
(340 km/h)
Speed of the tsunami

3,000 feet
(900 m)

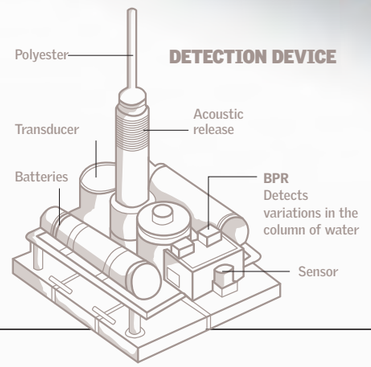
31 miles per hour
(50 km/h)
Speed of the Tsunami

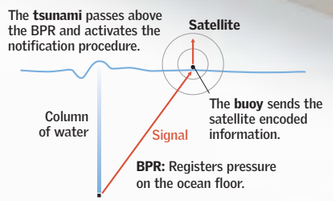
65 feet
(20 m)

Between 5 and 30 minutes before the tsunami arrives, the sea level suddenly drops.

Buildings on the coast may be damaged or destroyed.

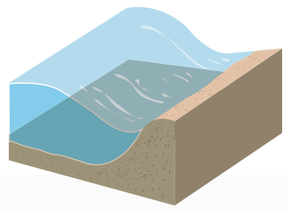
DETECTION DEVICE



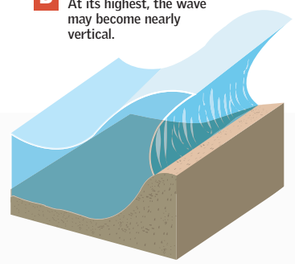


WHEN THE WAVE HITS THE COAST

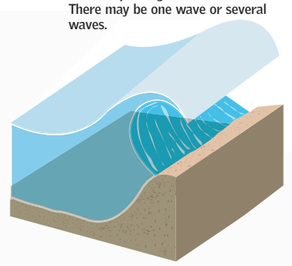
A **Sea level drops abnormally low.** Water is "sucked" away from the coast by the growing wave.



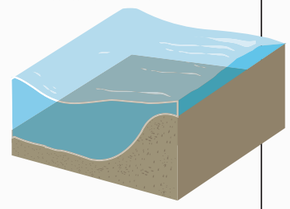
B **The giant wave forms.** At its highest, the wave may become nearly vertical.



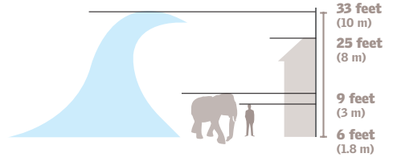
C **The wave breaks along the coast.** The force of the wave is released in the impact against the coast. There may be one wave or several waves.



D **The land is flooded.** The water may take several hours or even days to return to its normal level.



COMPARISON OF THE SIZE OF THE WAVE



33 feet (10 m)
Typical height a major tsunami can reach.

After a catastrophe

The illustration shows a satellite image of Khao Lak, in the coastal province of Phang Nga in southwestern Thailand. The picture was taken three days after the great tsunami of Dec. 26, 2004, that was caused by the colliding Eurasian and Australian plates near Indonesia. This was the greatest undersea earthquake in 40 years. Below, the area as it looked two years earlier.

Everything swept away by the wave was left piled up on the beach.

Coastline before the tsunami

The coastline was devastated.

Bamboo Orchid Resort

CAPE PANKARANG

The tropical forests along the beach of Cape Pankarang were wiped out.

Palm Galleria Resort

Pankarang Beach Cottage

South Sea Pankarang

River levels rose after the catastrophe.

Blue Village Pankarang Resort

The river's mouth was completely flooded.

Dec. 29, 2004

The hypothetical line shows how far inland the tsunami reached. Over half a mile (1 km) of the coast was swept away by the tidal wave. Eighty percent of the surface in Khao Lak's tourist area was destroyed.

1,000

Deaths caused by the tsunami in this area alone.

Thailand had the greatest number of tourist deaths.

THAILAND

Latitude 16° N

Longitude 100° E

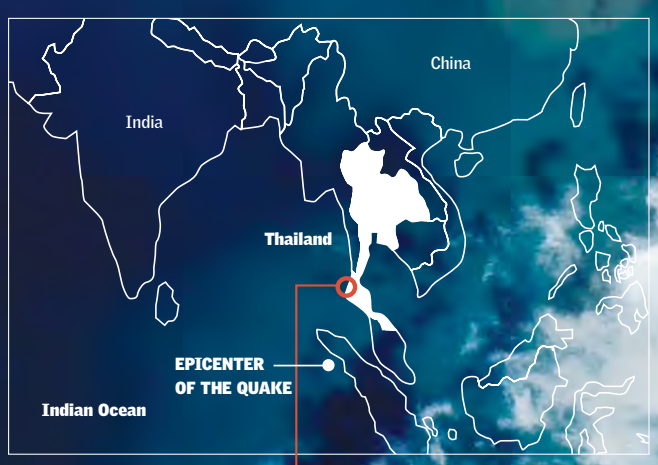
Surface area	198,114 square miles (513,115 sq km)
Population	63,100,000
Population density	289 people per square mile (112.9 people/sq km)
Tsunami-related deaths	5,248
Persons missing in tsunami	4,499

ANDAMAN SEA

Area flooded by the wave

3,300-4,900 feet (1,000-1,500 m)

Khuk Khak Beach



Many beaches lost all their sand.

Sofitel Magic Lagoon Resort

Grand Diamond Resort and Spa

Theptaro Lagoon Resort

Meteorological center

0 feet (m) 1,650 (500)

Jan. 13, 2003

Nearly two years before the tragedy. Wide areas of lush vegetation, fine, white sand beaches, and many buildings enhanced the natural attractions of this tourism center.

10:00 a.m.

Time when the wave hit the beach.

Surface area	28.3 million square miles (73.4 million sq km)
Percentage of Earth's surface	14%
Percentage of total volume of the oceans	20%
Length of plate boundaries (in focus)	745 miles (1,200 km)
Countries affected in 2004	21

Cause and Effect

On Dec. 26, 2004, an earthquake occurred that measured 9.0 on the Richter scale, the fifth greatest on record. The epicenter was 100 miles (160 km) off the west coast of Sumatra, Indonesia. This quake generated a tsunami that pummeled all the coasts of the Indian Ocean. The islands of Sumatra and Sri Lanka suffered the worst effects. India, Thailand, and the Maldives also suffered damage, and there were victims as far away as Kenya, Tanzania, and Somalia, in Africa.

Duration

The tremor lasted between 8 and 10 minutes, one of the longest on record. The waves took six hours to reach Africa, over 5,000 miles (8,000 km) away.

7:58
Local time when the tsunami was unleashed (00:58 universal time)

THE VICTIMS
On this map, the number of confirmed deaths and the number of missing persons in each country are added together, giving an estimated total death toll. In addition, 1,600,000 persons had to be evacuated.

230,507
Estimated dead

30 percent were children

SOMALIA
Pop. 8,863,338
289 dead

KENYA
Pop. 34,707,817
1 dead

TANZANIA
Pop. 37,445,392
13 dead

INDIA
Pop. 1.065 billion
18,045 dead

MALDIVES
Pop. 339,330
108 dead

SRI LANKA
Pop. 19,905,165
35,322 dead

BANGLADESH
Pop. 141,340,476
2 dead

MYANMAR
Pop. 42,720,196
600 dead

THAILAND
Pop. 64,865,523
8,212 estimated dead

INDONESIA
Pop. 238,452,952
167,736 dead

MALAYSIA
Pop. 23,522,482
74 dead

ARABIAN PLATE
INDIAN PLATE
AFRICAN PLATE
EURASIAN PLATE
PHILIPPINE PLATE
PACIFIC PLATE
ASIA
AFRICA
Indian Ocean
Pacific Ocean
GULF OF BENGAL
SUMATRA

Dhaka
Calcutta
Mandalay
Rangoon (Yangon)
Bangkok
Phuket
Banda Aceh
Vishakhapatnam
Bangalore
Madras
Cochin
Pulmoddai
Batticaloa
Colombo
Matara

0.4 inches per year (1 cm/year)
4 inches per year (10 cm/year)
0.4 inches per year (1.0 cm/yr)
0.4 inches per year (1.0 cm/yr)

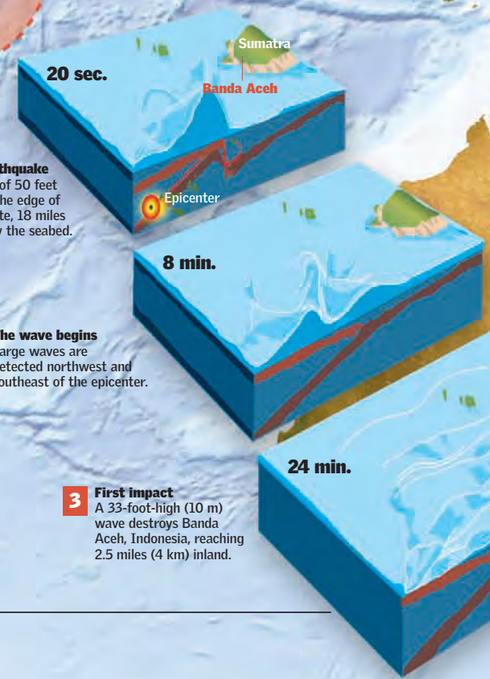
1h
2h
3h
4h
5h
6h

EPICENTER
3° 18′ N
95° 47′ E

Magnitude 9
Multiple aftershocks of up to magnitude 7.3.

500 miles per hour (800 km/h)
Speed of the first wave

LEGEND
- Most-affected areas
- Plate movements at different speeds
- 6h — Time it took the wave to reach the indicated dotted line.
- Movement of the wave.



1 Undersea earthquake
Displacement of 50 feet (15 m) along the edge of the Indian Plate, 18 miles (30 km) below the seabed.

2 The wave begins
Large waves are detected northwest and southeast of the epicenter.

3 First impact
A 33-foot-high (10 m) wave destroys Banda Aceh, Indonesia, reaching 2.5 miles (4 km) inland.

The tsunami's advance.

A seismic station in Australia detected the seismic movement that later caused the great tsunami that struck the nearest coastlines with waves more than 33 feet (10 m) high. An hour and a half later, the tsunami reached Sri Lanka and Thailand. The tsunami had seven crests, which reached the coasts at 20-minute intervals. By the time the tsunami arrived at the coast of Africa hours later, the waves had been greatly diminished.

Study and Prevention

NORTHRIDGE
The 1994 earthquake in this California city measured 6.7 on the Richter scale and caused approximately 60 deaths and damage estimated at a value of $40,000,000,000.

RISK AREAS 76-77
PRECISION INSTRUMENTS 78-79
CONTINUOUS MONITORING 80-81
STABLE BUILDINGS 82-83
ON GUARD 84-85
SAN FRANCISCO IN FLAMES 86-89
HISTORIC EARTHQUAKES 90-91

Predicting earthquakes is very difficult because of a large number of variables, because no two fault systems are alike. That is why populations that have settled in areas with high seismic risk have developed a number of strategies to help everyone know how to act should the earth begin to shake. California and Japan are examples of densely populated regions whose buildings, now designed according to a stable construction model, have saved many lives. There children are trained periodically at their schools: they do practice drills, and they know where to look for cover. Experts have learned many things about earthquakes in their attempt to understand the causes of these tremors, but they still are not able to predict when an earthquake will take place. ●

Risk Areas

A seismic area is found wherever there is an active fault, and these faults are very numerous throughout the world. These fractures are especially common near mountain ranges and mid-ocean ridges. Unfortunately, many population centers were built up in regions near these dangerous places, and, when an earthquake occurs, they become disaster areas. Where the tectonic plates collide, the risk is even greater.

Most-vulnerable regions

They are unpredictable, and among the most destructive of natural phenomena. Earthquakes shake the earth. They open and move it, and, within a few seconds, they can turn a peaceful city into the worst disaster area, an area in which seismic activity and a high population density coincide. But in the open country, where earthquakes have much less effect, we can conclude that it is not earthquakes, but buildings, that kill people.

9.2
Alaska, 1964
Lasted between three and five minutes and caused a tsunami responsible for 122 deaths.

8.3
San Francisco, 1906
Major fires contributed to the devastation of the city.

8.1
Mexico, 1985
Two days later there was a 7.6 aftershock. More than 11,000 people died.

6.8
Kobe, 1995
The city of Kobe and nearby villages were destroyed in only 30 seconds.

8.7
Assam, 1897
More than 1,600 people died in northwest India.

9.0
Sumatra, 2004
Tsunami in Asia
An earthquake near the island of Sumatra created 33-foot (10-m) waves and a human tragedy.

8.7
Lisbon, Portugal, 1755
More than 60,000 people died, and a tsunami followed the earthquake.

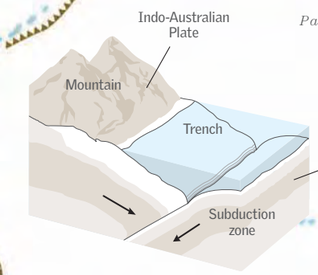
6.8
Armenia, 1988
Destroyed the city of Spitak and took more than 25,000 lives.

7.6
Kashmir, 2005
80,000 fatalities and losses valued at $653,170,000.

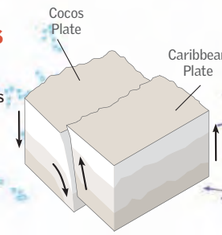
7.5
Iran, 1990
More than 60,000 dead. This was the worst disaster in Iran in the 20th century.

9.5
Chile, 1960
The most powerful earthquake ever registered: 5,700 people died and two million were left homeless.

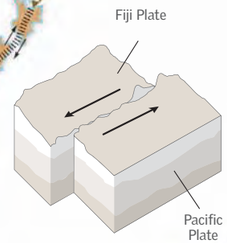
MARIANA TRENCH
The deepest marine trench on the planet, with a depth of 35,872 feet (10,934 m) below sea level. It is on the western side of the north Pacific and east of the Mariana Islands.



COCOS AND CARIBBEAN PLATES
Contact between these two plates is of the convergent type: the Cocos Plate moves under the Caribbean Plate, a phenomenon known as subduction. This causes a great number of tremors and volcanoes.

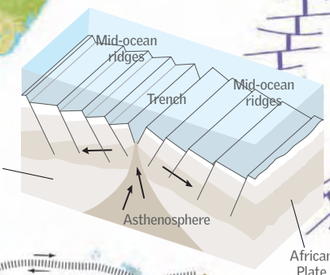


NEW ZEALAND FAULT
A large fault that moves horizontally, crosses the lithosphere, accommodating the movement between two large crust plates; it is a special type of directional plate called a transforming plate.



AFRICAN AND ARABIAN PLATES
The African Plate includes part of the Atlantic, Indian, and Antarctic oceans. To the north it borders with the Arabian Plate. When these two plates separated, they formed the Red Sea, which is still widening.

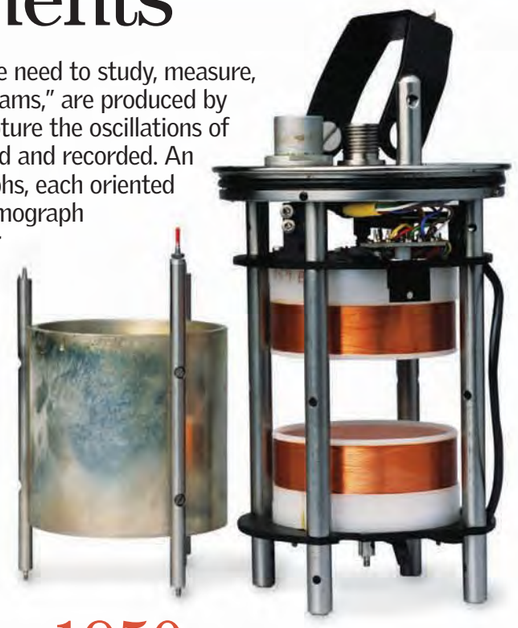
MID-OCEAN RIDGE
A submarine mountain range formed by the displacement of tectonic plates, these are active formations. These mountain systems are the longest in the world.



KEY
- Convergent boundary and direction
- Oceanic fault
- Transform fault
- Movement and direction of the oceanic fault
- Movement and direction of fault
- Epicenter
- Important earthquake
- Seismic area
- Disaster area

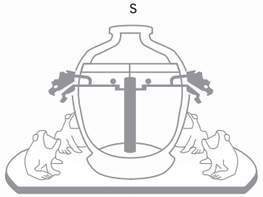
Precision Instruments

The destructive potential of earthquakes gave rise to the need to study, measure, and record them. Earthquake records, called "seismograms," are produced by instruments called "seismographs," which basically capture the oscillations of a mass and transform them into signals that can be measured and recorded. An earthquake is usually analyzed by means of three seismographs, each oriented in a unique direction at a given location. In this way one seismograph detects the vibrations produced from north to south, another records those from east to west, and a third detects vertical vibrations, those that go up and down. With these three instruments, a seismic event can be reconstructed.



Seismometers in History

Modern seismometers have digital mechanisms that provide maximum precision. The sensors are still based on seismic energy moving a mechanical part, however, and that is essentially the same principle that operated the first instrument used to evaluate earthquakes. It was invented by a Chinese mathematician almost 2,000 years ago. Beginning with his invention, the mechanism has been perfected to what it is today.



HOW IT WORKS The oscillating mass vibrates when an earthquake takes place. The "dragons," joined to the pendulum by a rigid bar, hold small balls in a delicate equilibrium.

Seismic Wave

123

HENG'S SEISMOSCOPE

The first known seismometer was Chinese. The metallic pendulum mass hung from the cover of a large bronze jar. The small balls fell from the mouths of the dragons to the mouths of the frogs, depending on the direction of the seismic movement. Some of these models were 6 feet (2 m) tall.

ZHANG HENG
Chinese mathematician, astronomer, and geographer (AD 78-139), also invented the odometer, calculated the number pi as the square root of 10 (3.16), and corrected the calendar.

1906

BOSCH-OMORI SEISMOMETER

Is a horizontal pendulum with a pen that makes a mark directly on a paper roll. With it, Omori, a Japanese scientist, registered the 1906 earthquake in San Francisco.

1950

PORTABLE SEISMOMETER

Their strong structure allowed these seismometers to be installed in the field. This model translated movement to electric impulses so the signal could be transmitted over some distance.

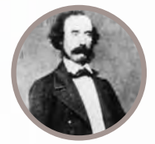
1980

WILMORE PORTABLE SEISMOMETER

A sensitive mass vibrates and moves to the rhythm of the seismic energy inside this tube-shaped mechanism. An electromagnet translates this vibration to electric signals, which are transmitted to a computer that records the data.

Pioneers of seismology

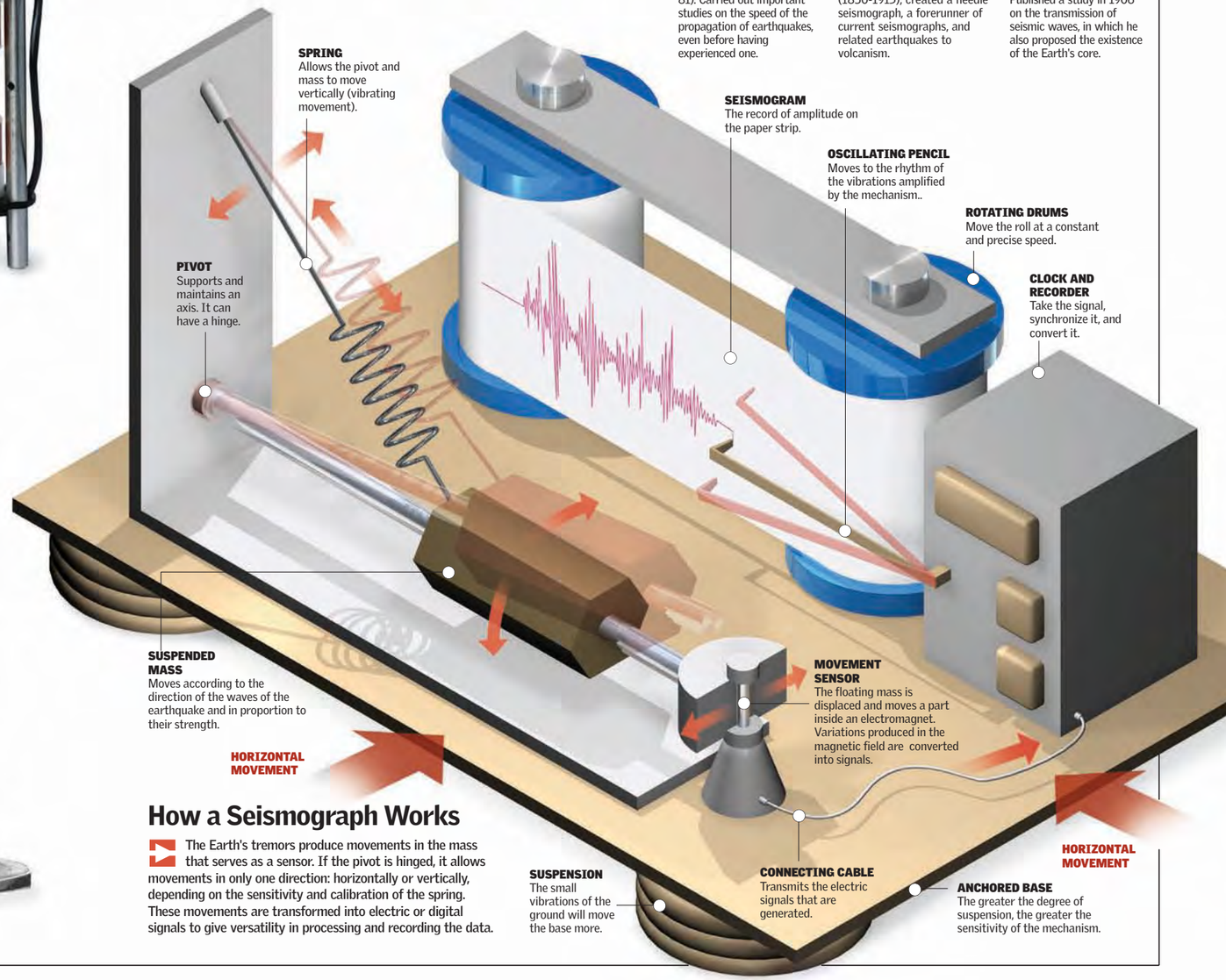
The defining principle of modern seismology emerged from relating earthquakes to the movement of the continents, but that did not take place until well into the 20th century. Starting in the 19th century, however, many scholars contributed elements that would be indispensable.



ROBERT MALLET
From Dublin, Ireland (1810-81). Carried out important studies on the speed of the propagation of earthquakes, even before having experienced one.

JOHN MILNE
British geologist and engineer (1850-1913), created a needle seismograph, a forerunner of current seismographs, and related earthquakes to volcanism.

RICHARD OLDHAM
British (1858-1936). Published a study in 1906 on the transmission of seismic waves, in which he also proposed the existence of the Earth's core.



How a Seismograph Works

The Earth's tremors produce movements in the mass that serves as a sensor. If the pivot is hinged, it allows movements in only one direction: horizontally or vertically, depending on the sensitivity and calibration of the spring. These movements are transformed into electric or digital signals to give versatility in processing and recording the data.

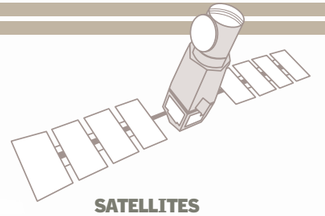
Continuous Movement

Humankind has tried throughout history to find a way to predict earthquakes. Today, this is done through the installation of seismic observatories and of various field instruments that gather information and compare it to the data sent by scientists from other locations. Based on these records, it is possible to evaluate the chances that a great earthquake is developing and act accordingly.

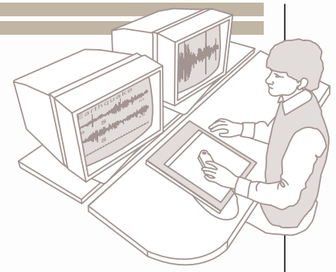
Seismologic Networks

Installing complex detection systems would not be of much use if the systems worked in an isolated manner and were not able to share the information they generated. There are national and international seismologic networks that, by means of communications technology, send their observations to other areas that might be affected.

NETWORK OF NETWORKS
Findings in an area can have repercussions at a great distance. The immediate availability of data allows for linked work.



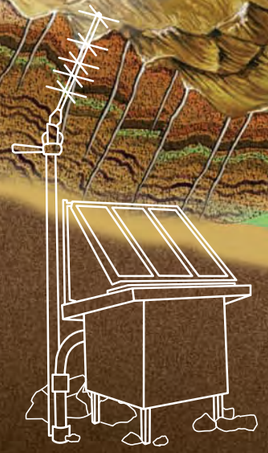
SATELLITES
Some are used by the GPS systems, but others are critical because they take photographs with extreme accuracy, and they are thus able to record indicators that can be communicated quickly to the base.



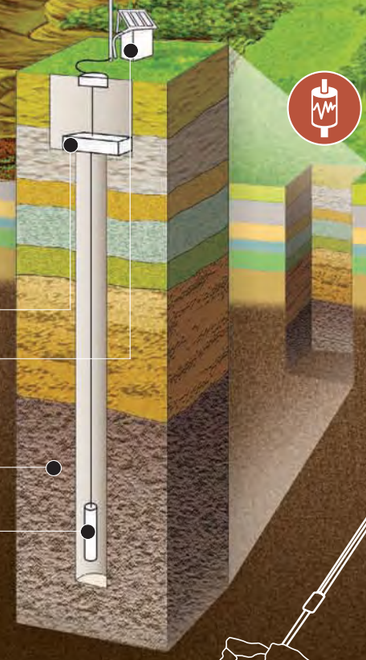
LABORATORY
Networking at the research centers allows for the comparison of data and provides a global vision that broadens the predictive power of science.

Observing from a Distance

Seismologists place instruments at fault lines in earthquake-prone areas. Later, at the seismologic observatory, the information taken by field instruments is compiled, and any significant change is noted. If anything suggests that an earthquake is about to take place, emergency services are alerted. Most of these instruments are automatic, and they send digital data through the telephone system.



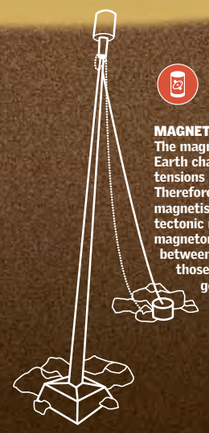
SEISMOMETER
Registers ground vibrations, their amplitude, and the direction in which they are produced. A seismometer can detect even the smallest tremor. Some, such as those pictured here, are powered by solar energy.



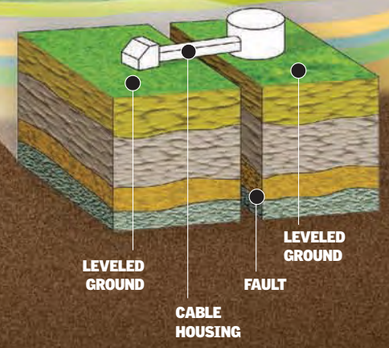
Placement of the Seismometer

The movement of the sensor mechanism, located under the ground, is converted into electric signals that are transmitted either to the recording module located on the surface or to computers.

GPS
The global positioning system (GPS) receiver picks up signals from the satellites and transmits them to the observatories. Because these signals register the receivers' exact locations, a change in their position over time indicates a movement in the crust.



MAGNETOMETER
The magnetic field of the Earth changes when the tensions between rocks vary. Therefore, a change in magnetism can indicate tectonic movement. The magnetometer can distinguish between these changes and those that are more general.



Placement of a Creep Meter

To measure the relative movement between the ends, two posts are fixed, one at each side of the fault, 6 feet (2 m) under the ground, or over the concrete base, at a fixed angle (but not at a right angle).

CREEP METER
Measures the movement between earthquakes or time interval between the two boundaries of a fault. It includes a tension system with a calibrated mechanism. Any movement between the ends alters the magnetic field.

Earthquakes cannot be predicted

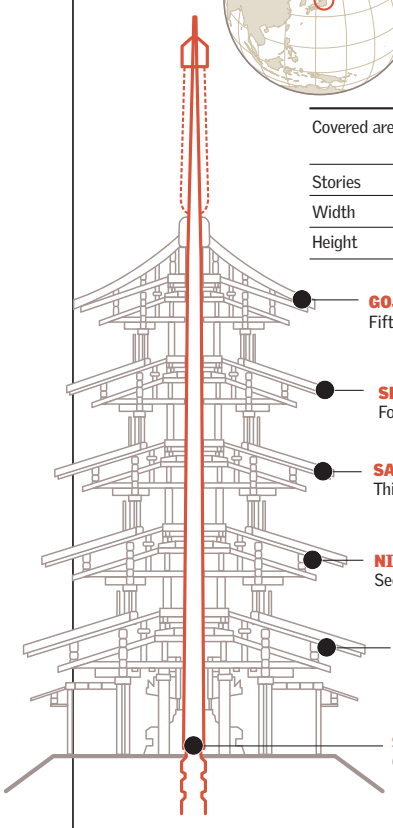
For a prediction system to be acceptable, it must be accurate and trustworthy. Therefore, it must have a small level of uncertainty regarding location and the timing, and it must minimize errors and false alarms. The cost of evacuating thousands of people, of providing lodging for them, and of making up for their loss of time and work for a false alarm would be unrecoverable. At this time there is no trustworthy method for predicting earthquakes.

Stable Buildings

In cities located in seismic areas, buildings must be designed and constructed with an earthquake-resistant structure that can adequately withstand the movements caused by an earthquake. Foundations are built with damping so that they can absorb the force of the seismic movement. Other buildings have a large metallic axis, around which the stories of the building can oscillate without falling. Currently the amount of knowledge on the effect of earthquakes on structures, as well as knowledge on the behavior of different materials, allows for the construction of less-vulnerable buildings.

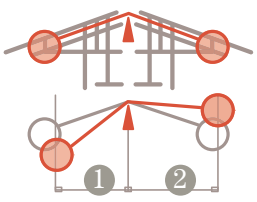
ROPPONGI HILLS
TOKYO, JAPAN
Latitude 36° N
Longitude 140° E

Covered area	**4,089,930 square feet (380.105 sq m)**
Stories	**54 (+6 underground)**
Width	**275 feet (84 m)**
Height	**780 feet (238 m)**

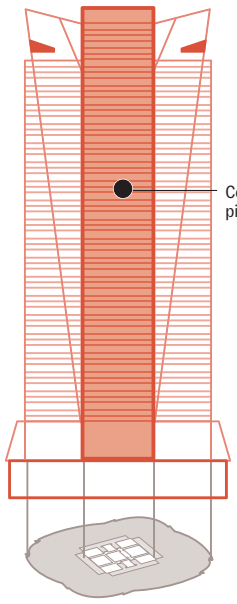


Why Pagodas in Japan Do Not Fall

Japanese pagodas have survived centuries of earthquakes. They are five stories tall, and higher sections of the building are smaller than lower parts. The pagodas are held up by a central pillar that acts as the only support for the building. During a quake, each floor balances independently, without transmitting the oscillating force to the other floors.



Swaying Principle
Each floor also has a symmetric structure. During an earthquake, the ends opposite the eaves act as a counterbalance to achieve equilibrium.



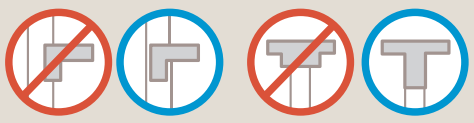
ROPPONGI HILLS TOWER
Located in Tokyo, its structure consists of simple geometric bodies, symmetrically placed, without any irregularities in shape. The tower is formed by a massive central framework and a lightweight and flexible exterior framework.

Earthquake-Resistant Architecture

There are many ways to design an earthquake-resistant structure: the distribution of walls, the joints between beams and columns, and geometric simplicity. There are also earthquake simulators, large platforms that shake a structure to test it. The simulators are used to test materials and study the forces that act on them. A building's true earthquake resistance, though, can be proven only when it has been built and has survived actual earthquakes.

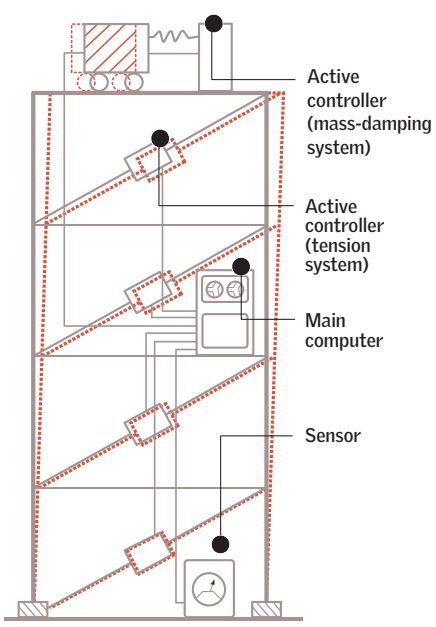
STRUCTURE
To avoid imbalances, the upper elements of a structure must be located over only a few axes, without any isolated vertical segments.

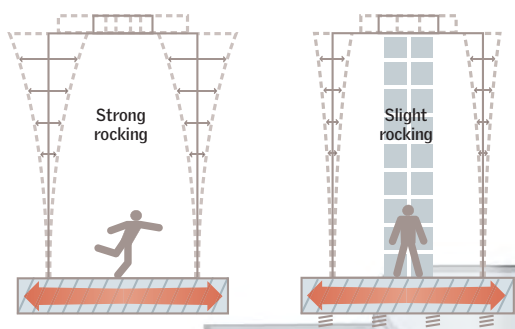
AVOIDANCE OF OFF-CENTER JOINTS
If the beam remains still when the wall moves, the joint breaks. Forces spread out over an axis with flexible material.



Suspension System

So that a building will suffer only small oscillations during an earthquake, it is isolated and built in a large trench, separated by special devices. In addition, because the higher floors move more than the lower ones, mechanical dampers are emplaced diagonally so as to be more highly tensioned on top than on the bottom. This makes the structure as a whole more flexible, but it also offers resistance to sudden variations.





THE INTELLIGENT BUILDING
When an earthquake is detected, a computer-controlled system provides variable compression to the dampers, which absorb the movements according to the height of the floor and the intensity of the vibrations.

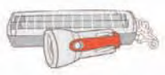
On Guard

When the earth shakes, nothing can stop it. Disaster seems inevitable, but, though it is inevitable, much can be done to diminish the extent of the catastrophe. Residents of earthquake-prone areas have incorporated a series of preventive measures to avoid being surprised and to help them act appropriately at home, at the office, or outdoors. These are basic rules of behavior that will help you survive.

Prevention

If you live in an earthquake-prone area, familiarize yourself with the emergency plans for the community where you live, plan how your family will behave in the event of an earthquake, know first aid, and know how to extinguish fires.

FIRST-AID KIT
Keep a first-aid kit, and keep your vaccinations up to date.



LIGHTS
Have emergency lighting, flashlights, a transistor radio, and batteries on hand.

SECURING OBJECTS
Secure heavy objects such as furniture, shelves, and gas appliances to the wall or to the floor.

BREAKERS
Have a breaker installed, and know how to shut off the electricity and the gas supply.

FOOD AND WATER
Store drinking water and nonperishable food.

FIRST AID
Learn first aid, and participate in community earthquake-response training.

During an earthquake

As soon as you feel the earth under your feet begin to move, look for a safe place, such as beneath a doorframe or under a table, to take cover. If you happen to be on a street, head to an open space such as a square or park. It is important to remain calm and to not be influenced by people who panic.

AT HOME

It is essential that the home be built following regulations for earthquake-resistant construction and that someone be in charge of shutting off the electricity and gas supplies.

AT THE OFFICE

Offices are usually located in areas conducive to bringing large groups of people together. Thus it is recommended that you remain where you are and not rush to the exits. When people panic, there is a greater probability of their being crushed by a crowd than by a building, especially in buildings that contain a lot of people.

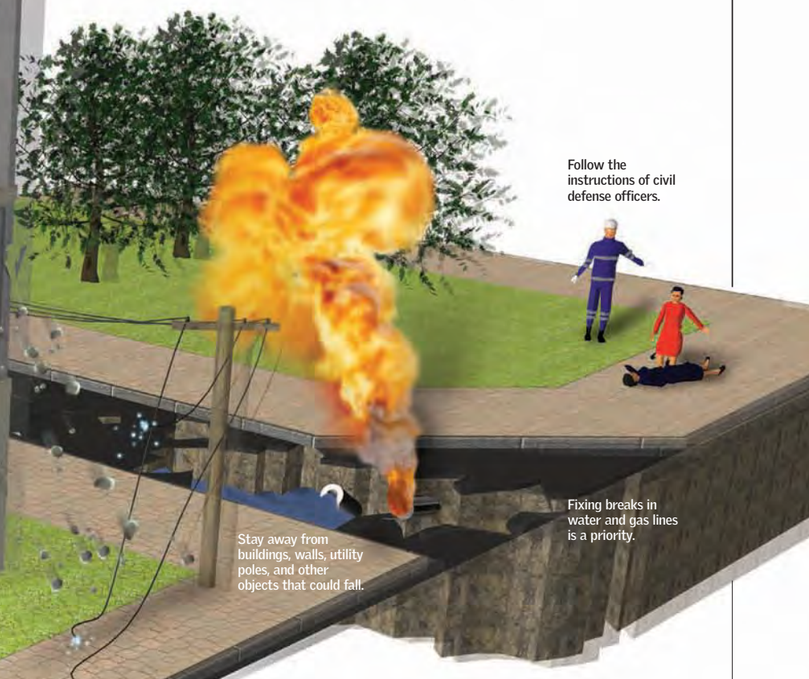
IN PUBLIC PLACES

When you are outside, it is important to keep away from tall buildings, light poles, and other objects that could fall. The safest course of action is to head to a park or other open space. If the earthquake takes you by surprise while you are driving, stop and remain in the car, but make sure you are not close to any bridges.

Coastlines

Head toward open spaces such as squares and parks, and move away from any trees to the extent possible.

Do not approach the coastline because of the possibility of a tsunami. Also avoid rivers, which could develop strong currents.



Rescue Tasks

Once the earthquake ends, rescue tasks must begin. At this stage it is imperative to determine whether anyone is injured and to apply first aid. Do not move injured people who have fractures, and do not drink water from open containers.

RESCUERS
The first priority after an earthquake is to search for survivors..

DOGS
Specially trained animals with protective helmets and masks can search for people under the rubble.

TRANSPORTATION
It is important to keep access routes to affected areas open to ensure entry by emergency teams.

San Francisco in Flames

The earthquake that shook San Francisco on April 18, 1906, was a major event: in only a few seconds, a large part of one of the most vital cities of the United States was reduced to rubble. Suddenly, centuries of pent-up energy was released when the earthquake, measuring 8.3 on the Richter scale, devastated the city. Though the earthquake destroyed many buildings, the worst damage was caused by the fires that destroyed the city in the course of three days, forcing people to flee their homes.

April 18

1 EVERYTHING STARTED LIKE THIS.
On April 18, 1906, at 5:12 a.m., the Pacific Plate experienced movement of approximately 19 feet (6 m) along its 267-mile (430-km) length along the northern San Andreas fault. The earthquake's epicenter lay 39 miles (64 km) north of San Francisco. In seconds, the earth began to move, and the majority of the city's buildings collapsed. The trolleys and carriages that were moving through the cobblestoned streets of the city were reduced to rubble.

CITY HALL
The facade was crowned by a dome that was supported by a system of columns on a steel structure. It was considered one of the city's most beautiful buildings.

GAS LIGHTING
Gas lighting was one of the signs of progress that gave prominence to the city.

History of City Hall

Until the earthquake struck, City Hall had been the seat of city government and the symbol of the city. Built in the second half of the 19th century, it represented a time of accelerated growth, powered by the gold riches of the state of California. Construction began on Feb. 22, 1870, and ended 27 years later, after many revisions to architect Auguste Laver's original project. While it stood, City Hall was said to have been constructed with bricks held together with corruption, typical of a time of easy money and weak institutions. The total cost of the work rose to a little more than $6,000,000 of that time, and, according to current calculations, it is estimated that it was prepared to withstand an earthquake up to a magnitude of 6.6. Only the dome and the metal structure were left standing. The remnants of the building were demolished in 1909.

THE FACE OF THE BUILDING COLLAPSED.
The facade collapsed completely on top of the rotunda at its base.

UNITED STATES
SAN FRANCISCO, CALIFORNIA
Latitude 42° 40′ N
Longitude 122° 18′ W

Surface area	46 square miles (120 sq km)
Population	739,426
Population density	16,000 people per square mile (6,200 people/sq km)
Perceptible earthquakes felt annually	100 - 150
Total earthquakes per year	~ 10,000

April 20

3 THE GREAT FIRE
Two days later, what had begun as a localized fire had become an inferno that consumed the city. There were mass evacuations of people to distant areas, while the army dynamited some buildings. Firefighters had to control the flames using seawater.

5:12 a.m.

2 THE EARTHQUAKE
Not only was the earthquake extremely violent, but it oscillated in every direction for 40 seconds. People left their houses and ran down the streets, completely stunned and blinded by fear. Many buildings split open, and others became piles of rubble. A post office employee related that "The walls were thrown into the middle of the rooms, destroying the furniture and covering everything with dust."

3 years

4 REBUILDING
The city reemerged from the ashes, powered by its wealth and economic importance. Losses are estimated to have reached $5,000,000,000 in present-day dollars, and, until Hurricane Katrina struck in 2005, the 1906 earthquake was the greatest natural disaster the United States had experienced.

Clearing the Rubble

It is calculated that some 3,000 people died in the 1906 catastrophe, trapped in their destroyed homes or burned by the fire the earthquake started. In the following weeks, the army, firefighters, and other workers deposited the rubble in the bay, forming new land, which is today known as the Marina District. Little by little, traffic resumed in the major streets, and the trolley system was reestablished. Six weeks after the earthquake, banks and stores opened for business.

Workers pose while they demolish a house.

WORKERS

By Saturday, April 21, some 300 plumbers had entered the city to reestablish services, mainly the water system. During the following weeks, thousands of workers tore down unstable buildings, prepared the streets for traffic, and cleared the city of rubble. Nearly 15,000 horses were used to haul rubble.

FIELD LUNCH

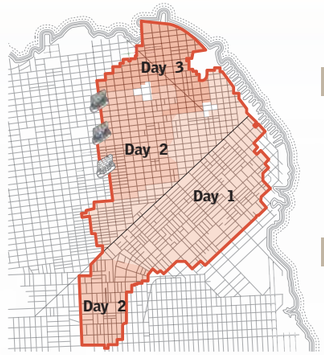
The army set up kitchens in the camps. There was always food in these field kitchens, and there was even a free ration of tobacco for every person.

Three Days of Fire

The great fire that followed the earthquake expanded quickly. Firefighters, in a desperate attempt to block the spread of the fire, used explosives to make firebreaks because there was no water supply available. The army evacuated the area, and people could not take anything with them. During the three days when the city burned, it is speculated that many homeowners burned their houses that had been partially destroyed by the earthquake, in order to be able to collect insurance money. Other things that contributed to the fire were the intentional explosions that, at first badly implemented, spread the fire. By the fourth day, the center of the city was reduced to ashes.

1 The fire began in the Market Street area, south of the city in the worker's district, where many houses were made of wood.

2 On the second day, the fire spread west. About 300,000 people were evacuated from the bay in ferries.



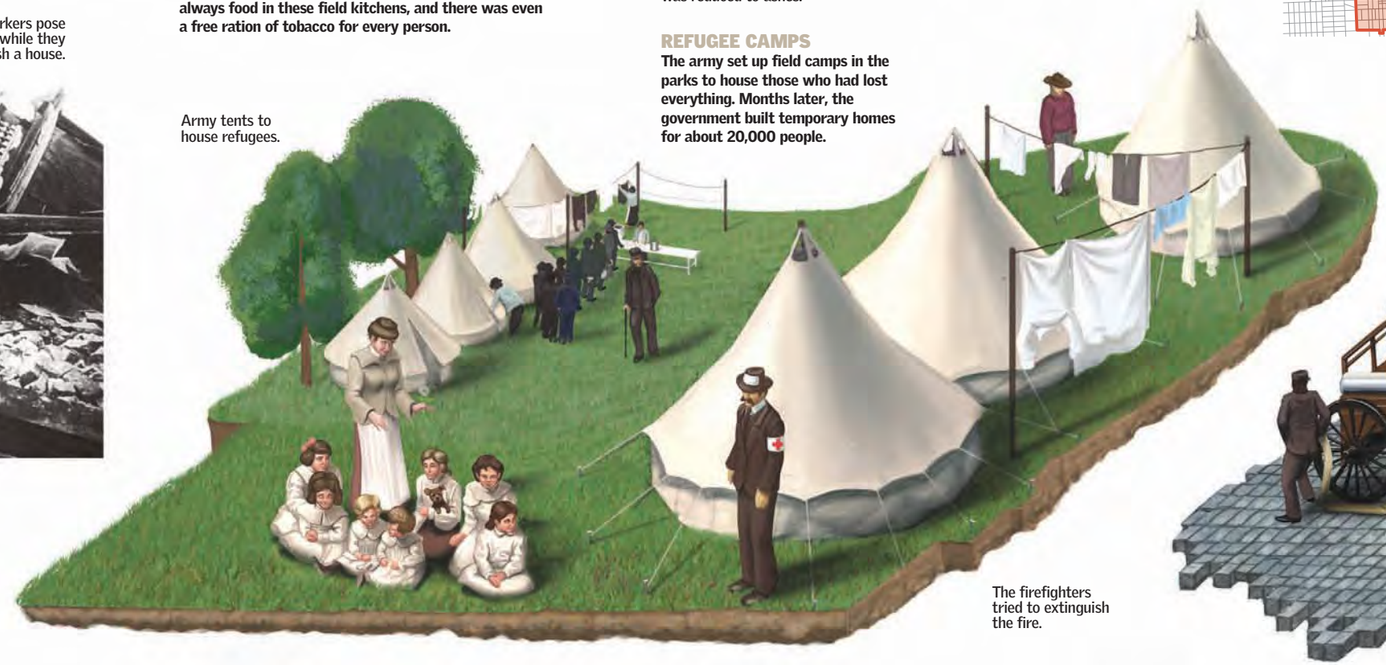
3 During the third day, the fire swept through Chinatown and North Beach, causing heavy damage to the Victorian homes on North Beach hill.

4 Once the fire was extinguished, Russian Hill and Telegraph Hill (shown as white spots) were still intact, as was the port.

REFUGEE CAMPS

The army set up field camps in the parks to house those who had lost everything. Months later, the government built temporary homes for about 20,000 people.

Army tents to house refugees.



The firefighters tried to extinguish the fire.

SHORTLY AFTERWARD

This panoramic photograph shows the destruction of the city. Despite the destruction, many buildings were left standing.

SAINT MARY'S CHURCH

CHINATOWN
Was completely destroyed by the fire.

18,000

BUILDINGS OF THAT PERIOD
are still standing, despite the 1906 earthquake and the tremors that passed through the city afterward.

MERCHANT EXCHANGE
Built in 1903, it remained standing and was later refurbished.

MILLS BUILDING
This building in the financial district had been built in 1890.

28,000

BUILDINGS DEMOLISHED
The damage calculated to have been caused by the great earthquake. Many of these buildings, such as City Hall, were famous for their lavish architecture.

Historic Earthquakes

The Earth is alive. It moves, it shifts, it crashes and quakes, and it has done so since its origin. Earthquakes vary from a soft vibration to violent and terrorizing movements. Many earthquakes have gone down in history as the worst natural catastrophes ever survived by humanity. Lisbon, Portugal, 1755; Valdivia, Chile, 1960; and Kashmir, Pakistan, 2005, are only three examples of the physical, material, and emotional devastation in which an earthquake can leave a population. ●

1995

KOBE, JAPAN

Magnitude	6.8 (Richter)
Fatalities	6,433
Material losses	$100 billion

AN INFERNO

The great earthquake of Hanshin that occurred on Jan. 17, 1995, in Kobe, a Japanese port, left behind more than 6,000 dead, 38,000 injured, and 319,000 people who had to be housed in more than 1,200 emergency shelters. The Nagata District was one of the hardest-hit areas. Almost 80 percent of the victims died because the old wooden homes crumbled in the generalized fires that followed the earthquake.

AFTER THE HORROR. The world was shaken, looking at the horrendous images of how Kobe, the city by the sea, had been painfully broken to pieces.

1755

LISBON, PORTUGAL

Magnitude	8.7 (Richter)
Fatalities	62,000
Material losses	unknown

It was the Day of the Dead, and, at 9:20 in the morning, almost the entire population of Lisbon was at church. While mass was celebrated, the earth quaked, and this earthquake would be one of the most destructive and lethal in history. The earthquake unleashed a tsunami that was felt from Norway to North America and that took the lives of those who had sought shelter in the river.

1906

SAN FRANCISCO, U.S.

Magnitude	8.3 (Richter)
Fatalities	3,000
Material losses	$5 billion

The city was swept by the earthquake and by the fires that followed it. The quake was the result of the rupture of more than 40 miles of the San Andreas fault. It is the greatest earthquake in the history of the United States: 300,000 people were left homeless, and property losses reached millions in 1906 dollars. Buildings collapsed, the fires spread for three days, and the water lines were destroyed.

2004

SUMATRA, INDONESIA

Magnitude	9.0 (Richter)
Fatalities	230,507
Material losses	incalculable

An earthquake whose epicenter crossed the island of Sumatra, Indonesia, took place on December 26. This earthquake generated a tsunami that affected the entire Indian Ocean, primarily the islands of Sumatra and Sri Lanka, and reached the coasts of India, Thailand, the Maldives, and even Kenya and Somalia. This was a true human tragedy, and the economic damages were incalculable.

1960

VALDIVIA, CHILE

Magnitude	9.5 (Richter)
Fatalities	5,700
Material losses	$500 million

Known as the Great Chilean Earthquake, this was the strongest earthquake of the 20th century. The surface waves produced were so strong that they were still being registered by seismometers 60 hours after the earthquake. The earthquake was felt in various parts of the planet, and a huge tsunami spread through the Pacific Ocean, killing more than 60 people in Hawaii. One of the most powerful earthquakes in memory, its aftershocks lasted for more than a week. More than 5,000 people died, and nearly two million people suffered damage and loss.

1985

MEXICO CITY, MEXICO

Magnitude	8.1 (Richter)
Fatalities	11,000
Material losses	$1 billion

The city shook on September 19. Two days later, there was an aftershock measuring 7.6 on the Richter scale. In addition to 11,000 deaths, there were 30,000 injured, and 95,000 people were left homeless. As the Cocos Plate slid under the North American Plate, the North American Plate fractured, or split, 12 miles (20 km) inside the mantle. The vibrations of the ocean floor off the southwestern coast of Mexico provoked a tsunami and produced energy 1,000 times as great as that of an atomic bomb. Strong seismic waves reached as far east as Mexico City, a distance of 220 miles (350 km).

2005

KASHMIR, PAKISTAN

Magnitude	7.6 (Richter)
Fatalities	80,000
Material losses	$595 million

Also known as the Indian Subcontinent Earthquake, the North Pakistan Earthquake, and the South Asian Earthquake. It occurred on Oct. 8, 2005, in the Kashmir region between India and Pakistan. Because schools were in session when the earthquake struck (9:20 a.m.), many of the victims were children, who died when their school buildings collapsed. It was the strongest earthquake experienced by the region for a century. Three million people lost their homes. The most-heavily affected areas lost all their cattle. Entire fields disappeared under earth and rock. The epicenter was located near Islamabad, in the mountains of Kashmir, in an area governed by Pakistan.

Glossary

Aa

Type of lava flow that presents sharp projections on its surface when it hardens.

Abrasion

Modification of rock surfaces by friction and by the impact of other particles transported by wind, water, and ice.

Active Volcano

Volcano that erupts lava and gas at regular intervals.

Aerosol

Small particles and drops of liquid scattered in the air by volcanic gases.

Aftershock

Small temblor or quake produced as rock settles into place after a major earthquake.

Aseismic

The characteristic of a building designed to withstand oscillations, or of areas with no seismic activity.

Aseismic Region

Tectonically stable region of the Earth, where there are almost no earthquakes. For example, the Arctic region is aseismic.

Ashfall

Phenomenon in which gravity causes ash (or other pyroclastic material) to fall from a smoke column after an eruption. The distribution of the ash is a function of wind direction.

Asthenosphere

Internal layer of the Earth that forms part of the mantle.

Avalanche

Rapid movement of enormous volumes of rock and other materials caused by instability on the flanks of the volcano. The instability can be caused by the intrusion of magma into the structure of the volcano, by a large earthquake, or by the weakening of the volcano's structure by hydrothermal variation, for example.

Ballistic (Fragment)

A lump of rock expelled forcefully by a volcanic eruption and that follows a ballistic or elliptical trajectory.

Baltic

Of or pertaining to the Baltic Sea, or to the territories along it.

Batholith

Massive body of magma that results from an intrusion between preexisting layers.

Caldera

Large, round depression left when a volcano collapses onto its magma chamber.

Convection Currents

Vertical and circular movement of rock material in the mantle but found exclusively in the mantle.

Convergent Boundary

Border between two colliding tectonic plates.

Core

Central part of the Earth, with an outer boundary 1,800 miles (2,900 km) below the Earth's surface. The core is believed to be composed of iron and nickel—with a liquid outer layer and a solid inner core.

Crater

Depression on the peak of a volcano, or produced by the impact of a meteorite.

Crust

Outermost, rigid part of the Earth, made up mostly of basaltic rocks (underneath the oceans) and of rocks with a higher silicate content (in the continents).

Density

Ratio of a body's mass to its volume. Liquid water has a density of 62.4 pounds per cubic foot (1 g/cu cm).

Dike

Tabular igneous intrusion that crosses through layers of surrounding rock.

Dome

Cup-shaped bulge with very steep sides, formed by the accumulation of viscous lava. Usually a dome is formed by andesitic, dacitic, or rhyolitic lava, and the dome can reach a height of many hundreds of feet.

Duration of Earthquake

Time during which the shaking or tremor of an earthquake is perceptible to humans. This period is always less than that registered by a seismograph.

Earthquake

Vibration of the Earth caused by the release of energy.

Eon

The largest unit of time on the geologic scale, of an order of magnitude greater than an era.

Epicenter

Point on the Earth's surface located directly above the focus of an earthquake.

Epicentral Area

Region around the epicenter of an earthquake, usually characterized by being the area where the shaking is most intense and the earthquake damage is greatest.

Epicentral Distance

Distance along the Earth's surface from the point where an earthquake is observed to the epicenter.

Extinct Volcano

Volcano that shows no signs of activity for a long period of time, considered to have a very low probability of erupting.

Fault Displacement

Slow, gradual movement produced along a fault. It is characterized by not generating an earthquake or tremor.

Focus

Internal zone of the Earth, where seismic waves are released, carrying the energy held by rocks under pressure.

Fumarole

Emission of steam and gas, usually at high temperatures, from fractures or cracks in the surface of a volcano or from a region with volcanic activity. Most of the gas emitted is steam, but fumarole emissions can include gases such as CO2, CO, SO2, H2S, CH4, HCl, among others.

Geothermal Energy

Naturally heated steam used to generate energy.

Geyser

Spring that periodically expels hot water from the ground.

Gondwana

Southern portion of Pangea, which at one time included South America, Africa, Australia, India, and Antarctica.

Hot Spot

Point of concentrated heat in the mantle capable of producing magma that shoots up to the Earth's surface.

Hydrothermal Alteration

Chemical change in rocks and minerals, produced by an aqueous solution that is rich in volatile chemical elements found at high temperature and that rises from a magma body.

Igneous Activity

Geologic activity involving magma and volcanic activity.

Incandescent

A property of metal that has turned red or white because of heat.

Lahar

Mudflows produced on the slopes of volcanoes when unstable layers of ash and debris become saturated with water and flow downhill.

Lapilli

Fragments of rock with a diameter between 0.06 and 1.3 inches (2 and 32 mm) expelled during a volcanic eruption.

Lava

Magma, or molten rock, that reaches the Earth's surface.

Lava Bombs

Masses of lava that a volcano expels, which have a diameter equal to or greater than 1.2 inches (3.2 cm).

Lava Flow

River of lava that flows out of a volcano and runs along the ground.

Liquefaction

Transformation of ground from solid to fluid state through the action of an earthquake.

Lithosphere

Rigid part of the outer layer of the Earth, formed by the crust and the outer layer of the mantle. This is the layer that is destroyed in subduction zones and that grows in mid-ocean ridges.

Magma

Mass of molten rock deep below the surface, which includes dissolved gas and crystals. When magma has lost its gases and reaches the surface, it is called lava. If magma cools within the Earth's crust, it forms plutonic rocks.

Magma Chamber

Section within a volcano where incandescent magma is found.

Mantle

Layer between the Earth's crust and the outer core. Its lower part, the asthenosphere, is partially molten. The more superficial and less-fluid outer part is called the lithosphere.

Mid-Ocean Ridge

An elongated mountain range on the ocean floor, which varies between 300 and 3,000 miles (500 and 5,000 km) in breadth.

Neck

Column of lava that has solidified inside a volcano.

Normal Fault

Fracture in rock layers where the ground is being stretched, which generally causes the upper edge to sink relative to the lower part.

Ocean Trench

Long, narrow, extremely deep area of the ocean floor formed where the edge of an oceanic tectonic plate sinks beneath another plate.

Pahoehoe Lava

Lava with a smooth surface that has a ropelike form.

Pelean Eruption

Type of volcanic eruption with a growing dome of viscous lava that may be destroyed when it collapses because of gravity or brief explosions. Pelean eruptions produce pyroclastic flows or burning clouds. The term comes from Mount Pelée in Martinique.

Permeable Layers

Strata of the Earth's crust that allow water to reach deeper layers.

Plate Tectonics

Theory that the Earth's outer layer consists of separate plates that interact in various ways, causing earthquakes and forming volcanoes, mountains, and the crust itself.

Plinian Eruption

Extremely violent and explosive type of volcanic eruption that continuously expels large quantities of ash and other pyroclastic materials into the atmosphere, forming an eruption column typically 5 to 25 miles (8 to 40 km) high. The term honors Pliny the Younger, who observed the eruption of Mount Vesuvius (Italy) in AD 79.

Plume

Column of hot rock that rises from within the mantle, inside of which the rock may melt.

Primary (P) Wave

Seismic wave that alternately compresses and stretches the ground along its direction of travel.

Pumice

Pale volcanic rock full of holes, which give it a low density. Its composition is usually acidic (rhyolitic). The holes are formed by volcanic gases that expand as volcanic material rises to the surface.

Pyroclastic Flow

Dense, hot mix of volcanic gas, ash, and rock fragments that flows rapidly down the sides of a volcano.

Reverse Fault

Fractures in rock layers where the ground is being compressed, which generally causes the upper edge to rise above the lower part in a plane inclined between 45 and 90 degrees from the horizontal.

Richter Scale

Measures the magnitude of an earthquake or of the energy it releases. The scale is logarithmic, such that an earthquake of magnitude 8 releases 10 times as much energy as a magnitude 7 quake. An earthquake's magnitude is estimated based on measurements taken by seismic instruments.

Rift Zone

Area where the crust is splitting and stretching, as shown by cracks in the rock. Such areas are produced by the separation of tectonic plates, and their presence causes earthquakes and recurrent volcanic activity.

Scale of Intensity

Scale used to measure the severity of movement of the ground produced by an earthquake. Degrees of intensity are assigned subjectively depending on how the tremor is perceived and according to the damage caused to buildings. A widely used scale is the Mercalli scale.

Secondary (S) Wave

Transverse or cross-section wave with motion perpendicular to the direction of its travel.

Seismic Event

Shaking of the ground caused by an abrupt and violent movement of a mass of rock along a fault, or fracture, in the crust. Active volcanoes cause a wide variety of seismic events.

Seismic Gap

Fault zone, or zone of a segment at the boundary between tectonic plates, with a known seismic history and activity, which records a period of prolonged calm, or of seismic inactivity, during which large amounts of elastic energy of deformation accumulate, and that, therefore, presents a greater probability of rupture and occurrence of a seismic event.

Seismic Hazard Calculation

Process of determining the seismic risk of various sites in order to define areas with similar levels of risk.

Seismic Risk

The probability that the economic and social effects of a seismic event will exceed certain preestablished values during a given period, for example, a certain number of victims, an amount of building damage, economic losses, etc. Also defined as the comparative seismic hazard of one site relative to another.

Seismic Wave

Wavelike movement that travels through the Earth as a result of an earthquake or an explosion.

Seismic Zone

Limited geographic area within a seismic region, with similar seismic hazard, seismic risk, and earthquake-resistant design standards.

Seismograph

Instrument that registers seismic waves or tremors in the Earth's surface during an earthquake.

Seismology

Branch of geology that studies tremors in the Earth, be they natural or artificial.

Shield Volcano

Large volcano with gently sloping flanks formed by fluid basaltic lava.

Silicon

One of the most common materials, and a component of many minerals.

Subduction

Process by which the oceanic lithosphere sinks into the mantle along a convergence boundary. The Nazca Plate is undergoing subduction beneath the South American Plate.

Subduction Zone

Long, narrow region where one plate of the crust is slipping beneath another.

Surface Wave

Seismic wave that travels along the Earth's surface. It is perceived after the primary and secondary waves.

Swarm of Earthquakes

Sequence of small earthquakes that occur in the same area within a short time period, with a low magnitude in comparison to other earthquakes.

Symmetry

Correspondence that exists in an object with respect to a center, an axis, or a plane that divides it into parts of equal proportions.

Tectonic Plates

Large, rigid sections of the Earth's outer layer. These plates sit on top of a more ductile and plastic layer of the mantle, the asthenosphere, and they drift slowly at an average rate of 1 inch (2.4 cm) or more per year.

Thrust Fault

A fracture in rock layers that is characterized by one boundary that slips above another at an angle of less than 45 degrees.

Transform Fault

Fault in which plate boundaries cause friction by sliding past each other in opposite directions.

Tremor

Seismic event perceived on the Earth's surface as a vibration or shaking of the ground, without causing damage or destruction.

Tsunami

Word of Japanese origin that denotes a large ocean wave caused by an earthquake.

Viscous

Measure of a material's resistance to flow in response to a force acting on it. The higher the silicon content, the higher the viscosity.

Volcanic Glass

Natural glass formed when molten lava cools rapidly without crystallizing. A solid-like substance made of atoms with no regular structure.

Volcanic Ring

Chain of mountains or islands located near the edges of the tectonic plates and that is formed as a result of magma activity associated with subduction zones.

Volcano

Mountain formed by lava, pyroclastic materials, or both.

Volcanology (Vulcanology)

Branch of geology that studies the form and activity of volcanoes.

Vulcanian Eruption

Type of volcanic eruption characterized by the occurrence of explosive events of brief duration that expel material into the atmosphere to heights of about 49,000 feet (15 km). This type of activity is usually linked to the interaction of groundwater and magma (phreatomagmatic eruption).

Water Spring

Natural source of water that flows out of the crust. The water comes from rainwater that seeps into the ground in one place and comes to the surface in another, usually at a lower elevation. Because the water is not confined in waterproof chambers, it can be heated by contact with igneous rock. This causes it to rise to the surface as hot springs.

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VOLCANOES AND EARTHQUAKES

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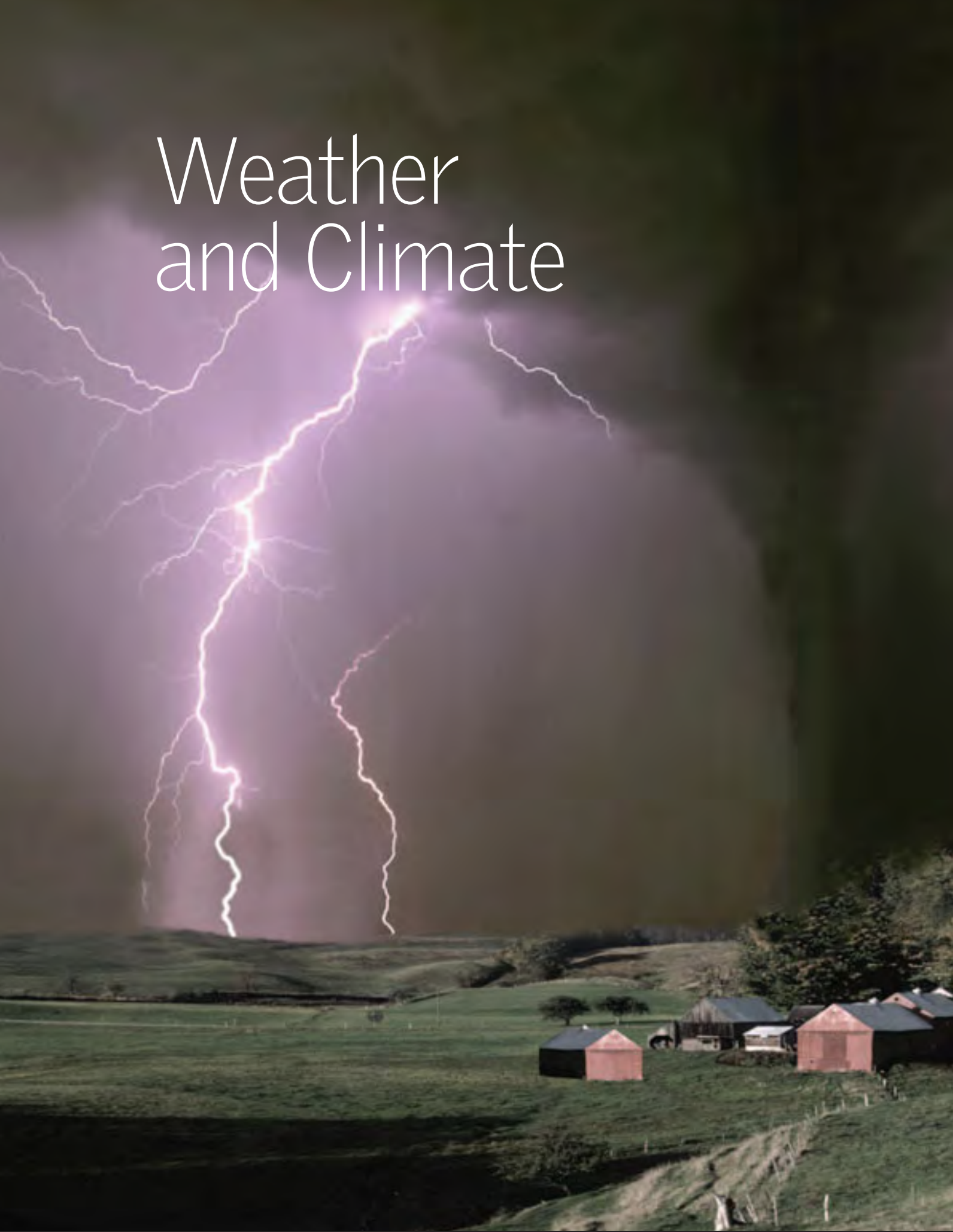

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Tornado during an electrical storm, in Oklahoma, 1973

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A Sum of Factors

STRONG WINDS AND TORRENTIAL RAINS
Between September 20 and September 25, 1998, Hurricane Georges lashed the Caribbean, leaving thousands of people homeless.

"The flutter of a butterfly's wings in Brazil can unleash a tornado in Florida." That was the conclusion arrived at in 1972 by Edward Lorenz after dedicating himself to the study of meteorology and trying to find a way of predicting meteorological phenomena that might put the lives of people at risk. In effect, the atmosphere is a system so complicated that many scientists define it as chaotic. Any forecast can rapidly deteriorate because of the wind, the appearance of a warm front, or an unexpected storm. Thus, the difference continues to grow geometrically, and the reality of the next day is not the one that was expected but entirely different: when there should have been sunshine, there is rain; people who planned to go to the beach find they have to shut themselves up in the basement until the hurricane passes. All this uncertainty causes many people who live in areas that are besieged by hurricanes or tropical storms to live in fear of what might happen, because they feel very vulnerable to changes in weather. It is also true that natural phenomena, such as tornadoes, hurricanes, and cyclones, do not in themselves cause catastrophes. For example, a hurricane becomes a disaster and causes considerable damage, deaths, and economic losses only because it strikes a populated area or travels over farmland. Yet in society, the idea persists that natural phenomena equate to death and destruction. In fact, experience shows that we have to learn to live with these phenomena and plan ahead for what might happen when they occur. In this book, along with spectacular images, you will find useful information about the factors that determine weather and climate, and you will be able to understand why long-term forecasts are so complicated. What changes are expected if global warming continues to increase? Could the polar ice caps melt and raise sea levels? Could agricultural regions slowly become deserts? All this and much more are found in the pages of the book. We intend to arouse your curiosity about weather and climate, forces that affect everyone.

Climatology

SATELLITE IMAGE
In this image of the Earth, one clearly sees the movement of water and air, which causes, among other things, temperature variations.

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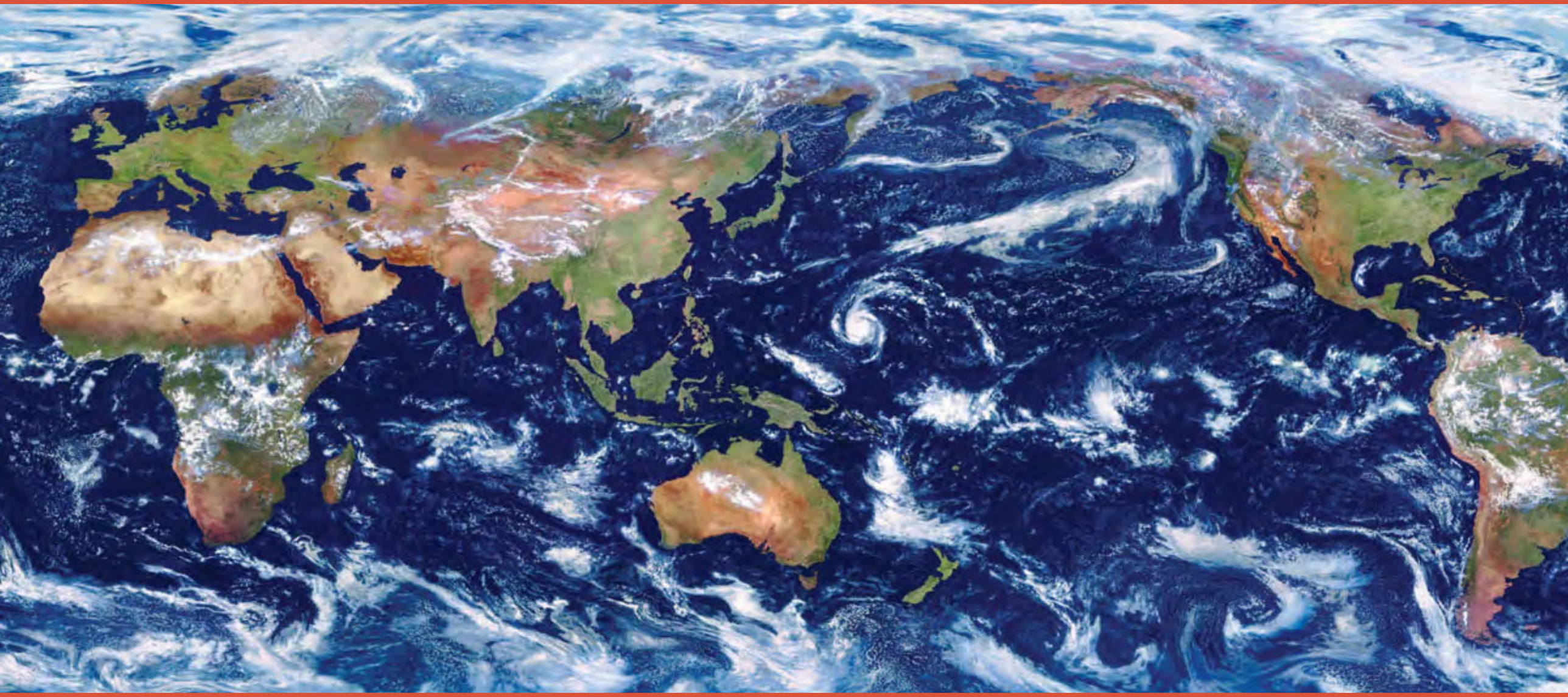
COLORS IN THE SKY 16-17



The constantly moving atmosphere, the oceans, the continents, and the great masses of ice are the principal components of the environment. All these constitute what is called the climatic system; they permanently interact with one another and transport water (as liquid or vapor), electromagnetic radiation, and heat.

Within this complex system, one of the fundamental variables is temperature, which experiences the most change and is the most noticeable. The wind is important because it carries heat and moisture into the atmosphere. Water, with all its processes (evaporation, condensation, convection), also plays a fundamental role in Earth's climatic system. ●

Global Equilibrium

The Sun's radiation delivers a large amount of energy, which propels the Earth's extraordinary mechanism called the climatic system. The components of this complex system are the atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere. All these components are constantly interacting with one another via an interchange of materials and energy. Weather and climatic phenomena of the past—as well as of the present and the future—are the combined expression of Earth's climatic system. ●

Atmosphere

Part of the energy received from the Sun is captured by the atmosphere. The other part is absorbed by the Earth or reflected in the form of heat. Greenhouse gases heat up the atmosphere by slowing the release of heat to space.

Biosphere

Living beings (such as plants) influence weather and climate. They form the foundations of ecosystems, which use minerals, water, and other chemical compounds. They contribute materials to other subsystems.

EVAPORATION
The surfaces of water bodies maintain the quantity of water vapor in the atmosphere within normal limits.

about 10%
ALBEDO OF THE TROPICAL FORESTS

WINDS
The atmosphere is always in motion. Heat displaces masses of air, and this leads to the general circulation of the atmosphere.

PRECIPITATION
Water condensing in the atmosphere forms droplets, and gravitational action causes them to fall on different parts of the Earth's surface.

HEAT

HEAT

Night and day, coastal breezes exchange energy between the hydrosphere and the lithosphere.

MARINE CURRENTS

HUMAN ACTIVITY

Hydrosphere

The hydrosphere is the name for all water in liquid form that is part of the climatic system. Most of the lithosphere is covered by liquid water, and some of the water even circulates through it.

3%
ALBEDO OF THE BODIES OF WATER

SOLAR RADIATION
About 50 percent of the solar energy reaches the surface of the Earth, and some of this energy is transferred directly to different layers of the atmosphere. Much of the available solar radiation leaves the air and circulates within the other subsystems. Some of this energy escapes to outer space.

Sun

Essential for climatic activity. The subsystems absorb, exchange, and reflect energy that reaches the Earth's surface. For example, the biosphere incorporates solar energy via photosynthesis and intensifies the activity of the hydrosphere.

ALBEDO
The percentage of solar radiation reflected by the climatic subsystems.

50%
THE ALBEDO OF LIGHT CLOUDS

SUN

Cryosphere

Represents regions of the Earth covered by ice. Permafrost exists where the temperature of the soil or rocks is below zero. These regions reflect almost all the light they receive and play a role in the circulation of the ocean, regulating its temperature and salinity.

80% ALBEDO OF RECENTLY FALLEN SNOW

Lithosphere

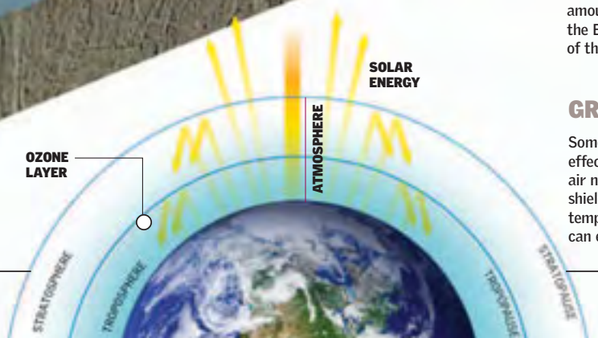
This is the uppermost solid layer of the Earth's surface. Its continual formation and destruction change the surface of the Earth and can have a large impact on weather and climate. For example, a mountain range can act as a geographic barrier to wind and moisture.

SMOKE
Particles that escape into the atmosphere can retain their heat and act as condensation nuclei for precipitation.

RETURN TO THE SEA

UNDERGROUND CIRCULATION
The circulation of water is produced by gravity. Water from the hydrosphere infiltrates the lithosphere and circulates therein until it reaches the large water reservoirs of lakes, rivers, and oceans.

ASHES
Volcanic eruptions bring nutrients to the climatic system where the ashes fertilize the soil. Eruptions also block the rays of the Sun and thus reduce the amount of solar radiation received by the Earth's surface. This causes cooling of the atmosphere.



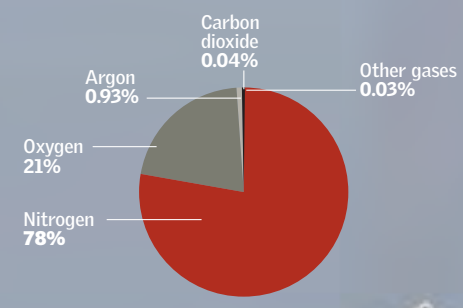
GREENHOUSE EFFECT

Some gases in the atmosphere are very effective at retaining heat. The layer of air near the Earth's surface acts as a shield that establishes a range of temperatures on it, within which life can exist.

Pure Air

The atmosphere is the mass of air that envelops the surface of the Earth. Its composition allows it to regulate the quantity and type of solar energy that reaches the surface of the Earth. The atmosphere, in turn, absorbs energy radiated by the crust of the Earth, the polar ice caps and the oceans, and other surfaces on the planet. Although nitrogen is its principal component, it also contains other gases, such as oxygen, carbon dioxide, ozone, and water vapor. These less abundant gases, along with microscopic particles in the air, have a great influence on the Earth's weather and climate.

GASES IN THE AIR



EXOSPHERE
This layer, which begins at an altitude of about 310 miles (500 km), is the upper limit of the atmosphere. Here material in plasma form escapes from the Earth, because the magnetic forces acting on them are greater than those of gravity.

GREENHOUSE EFFECT
Produced by the absorption of infrared emissions by the greenhouse gases in the atmosphere. This natural phenomenon helps to keep the Earth's surface temperature stable.

DISTANT ORBITS
Polar meteorological satellites orbit in the exosphere.

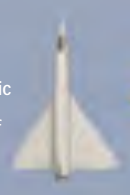
59° F (15° C)
AVERAGE TEMPERATURE OF THE EARTH'S SURFACE

THERMOSPHERE
Found between an altitude of 55 and 300 miles (90-500 km). The O_2 and the N_2 absorb ultraviolet rays and reach temperatures greater than 1,800° F (1,000° C). These temperatures keep the density of gases in this layer very low.

Auroras
Created in the upper layers of the atmosphere when the solar wind generates electrically charged particles

6%
of solar radiation is reflected by the atmosphere.

Military satellites
Air friction shortens their useful life.



Rocket probes
Used for scientific studies of the higher regions of the atmosphere

19%
of solar radiation is absorbed by the gases in the atmosphere.

Meteors
become superheated by friction with the molecules of the gas in the atmosphere. Particles that skip across the atmosphere are called shooting stars.

Cosmic rays
Come from the Sun and other radiation sources in outer space. When they collide with the molecules of gas in the atmosphere, they produce a rain of particles.

MESOSPHERE
Located between an altitude of 30 to 55 miles (50-90 km), it absorbs very little energy yet emits a large amount of it. This absorption deficit causes the temperatures to decrease from 60° F to -130° F (20° C to -90° C) in the upper boundary of the mesopause.

SOLAR RADIATION

Noctilucent clouds
The only clouds that exist above the troposphere. They are the objects of intense study.

20%
of solar radiation is reflected by the clouds.

Forecasts
Weather balloons are used to make weather forecasts. They record the conditions of the stratosphere.

STRATOSPHERE
Extends from an altitude of 6 miles to 30 miles (10-50 km). The band from 12 to 19 miles (20-30 km) has a high concentration of ozone, which absorbs ultraviolet radiation. A thermal inversion is produced in this layer that is expressed as an abrupt temperature increase beginning at an altitude of 12 miles (20 km).

The Ozone Layer
stops most of the Sun's ultraviolet rays.

Safe flights
The absence of meteorological changes in this region makes it safer for commercial flights.

Tropical storm clouds

TROPOSPHERE
Starts at sea level and goes to an altitude of six miles (10 km). It provides conditions suitable for life to exist. It contains 75 percent of the gases in the atmosphere. Meteorological conditions, such as the formation of clouds and precipitation, depend on its dynamics. It is also the layer that contains pollution generated by human activities.

51%
of solar radiation is absorbed by the Earth's surface.

4%
A small amount of solar radiation is reflected by the oceans and the ground.

High mountains
Any mountains higher than 5 miles (8 km) above sea level. The decrease of oxygen with altitude makes it difficult to breathe above 2.5 miles (4 km).

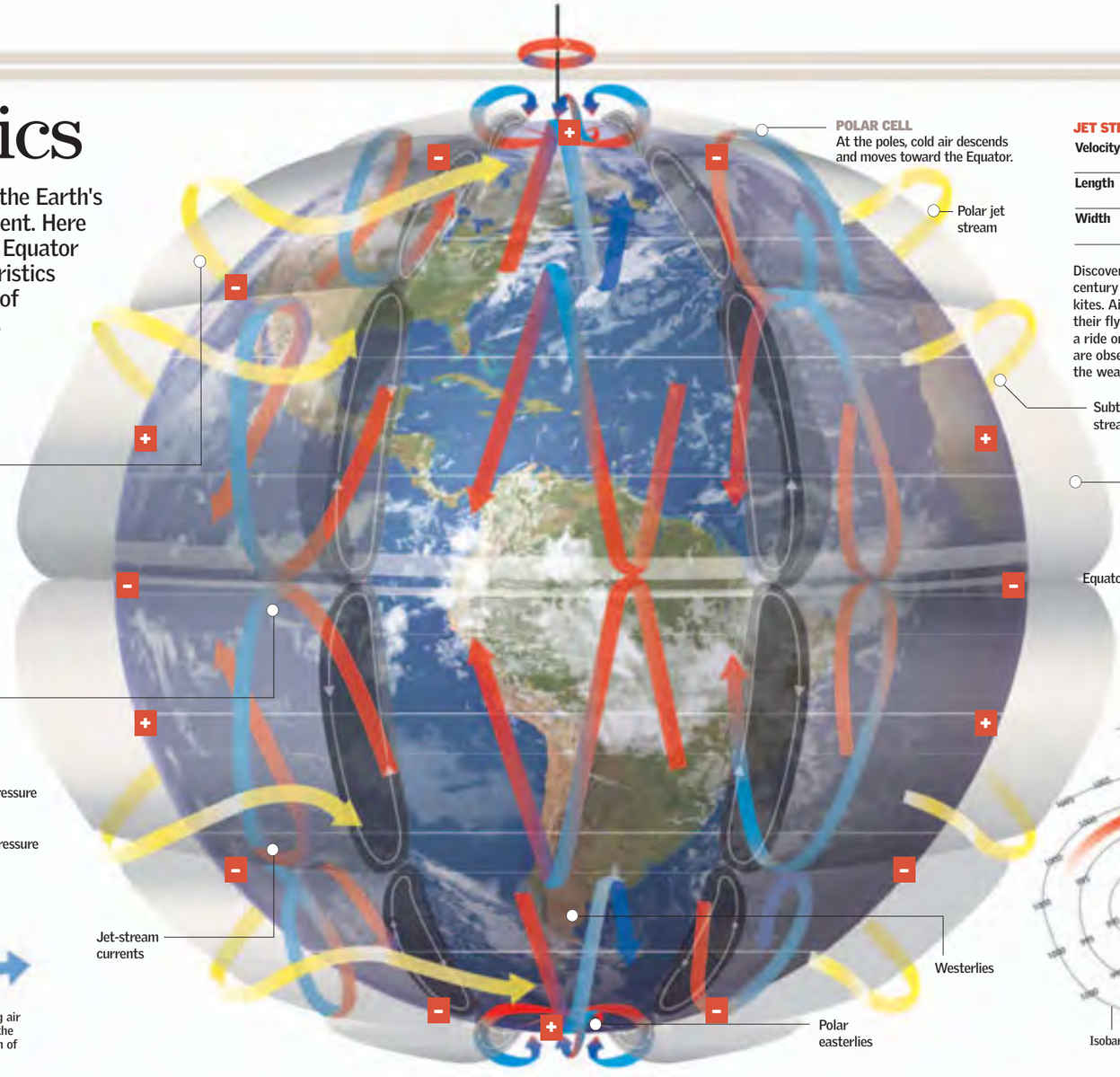
Cirrus

Atmospheric Dynamics

The atmosphere is a dynamic system. Temperature changes and the Earth's motion are responsible for horizontal and vertical air displacement. Here the air of the atmosphere circulates between the poles and the Equator in horizontal bands within different latitudes. Moreover, the characteristics of the Earth's surface alter the path of the moving air, causing zones of differing air densities. The relations that arise among these processes influence the climatic conditions of our planet.

CORIOLIS FORCE

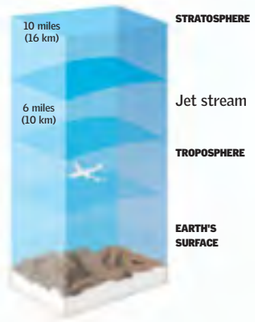
The Coriolis effect is an apparent deflection of the path of an object that moves within a rotating coordinate system. The Coriolis effect appears to deflect the trajectory of the winds that move over the surface of the Earth, because the Earth moves beneath the winds. This apparent deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The effect is only noticeable on a large scale because of the rotational velocity of the Earth.



JET STREAM

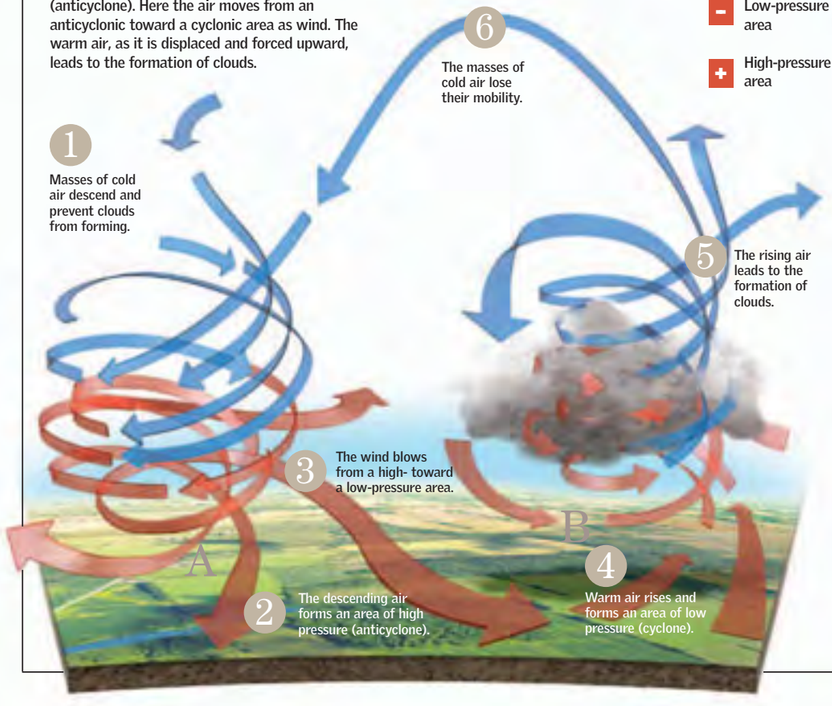
Velocity	55 to 250 miles per hour (90-400 km/h)
Length	1,000 to 3,000 miles (1,610-4,850 km)
Width	1 to 3 miles (1.6-4.8 km)

Discovered in the 19th century through the use of kites. Airplanes can shorten their flying time by hitching a ride on them. Their paths are observed to help predict the weather.



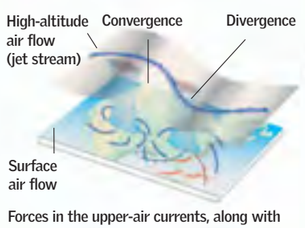
High and Low Pressure

Warm air rises and causes a low-pressure area (cyclone) to form beneath it. As the air cools and descends, it forms a high-pressure area (anticyclone). Here the air moves from an anticyclonic toward a cyclonic area as wind. The warm air, as it is displaced and forced upward, leads to the formation of clouds.

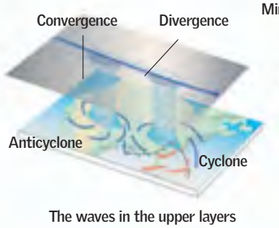


Changes in Circulation

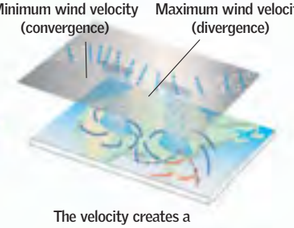
Irregularities in the topography of the surface, abrupt changes in temperature, and the influence of ocean currents can alter the general circulation of the atmosphere. These circumstances can generate waves in the air currents that are, in general, linked to the cyclonic zones. It is in these zones that storms originate, and they are therefore studied with great interest. However, the anticyclone and the cyclone systems must be studied together because cyclones are fed by currents of air coming from anticyclones.



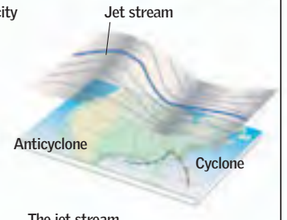
Forces in the upper-air currents, along with surface conditions, may cause air currents to flow together or may split them apart.



The waves in the upper layers are translated into cyclones and anticyclones at ground level.



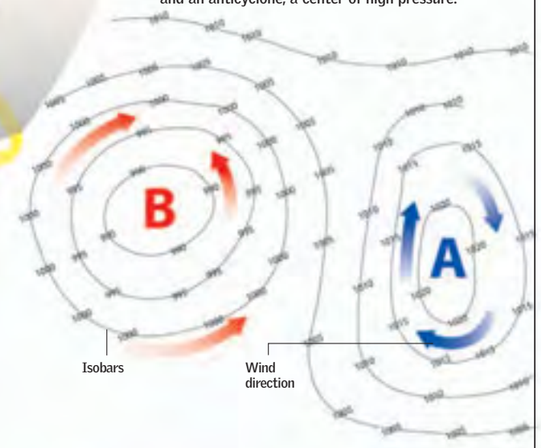
The velocity creates a difference in air concentration between different systems.



The jet stream generates air rotation, or vorticity.

WEATHER SYSTEMS ANALYSIS

The continuous lines are isobars (in this case, in the Southern Hemisphere), imaginary lines that connect points of equal pressure. They show depressions—centers of low pressure relative to the surroundings—and an anticyclone, a center of high pressure.

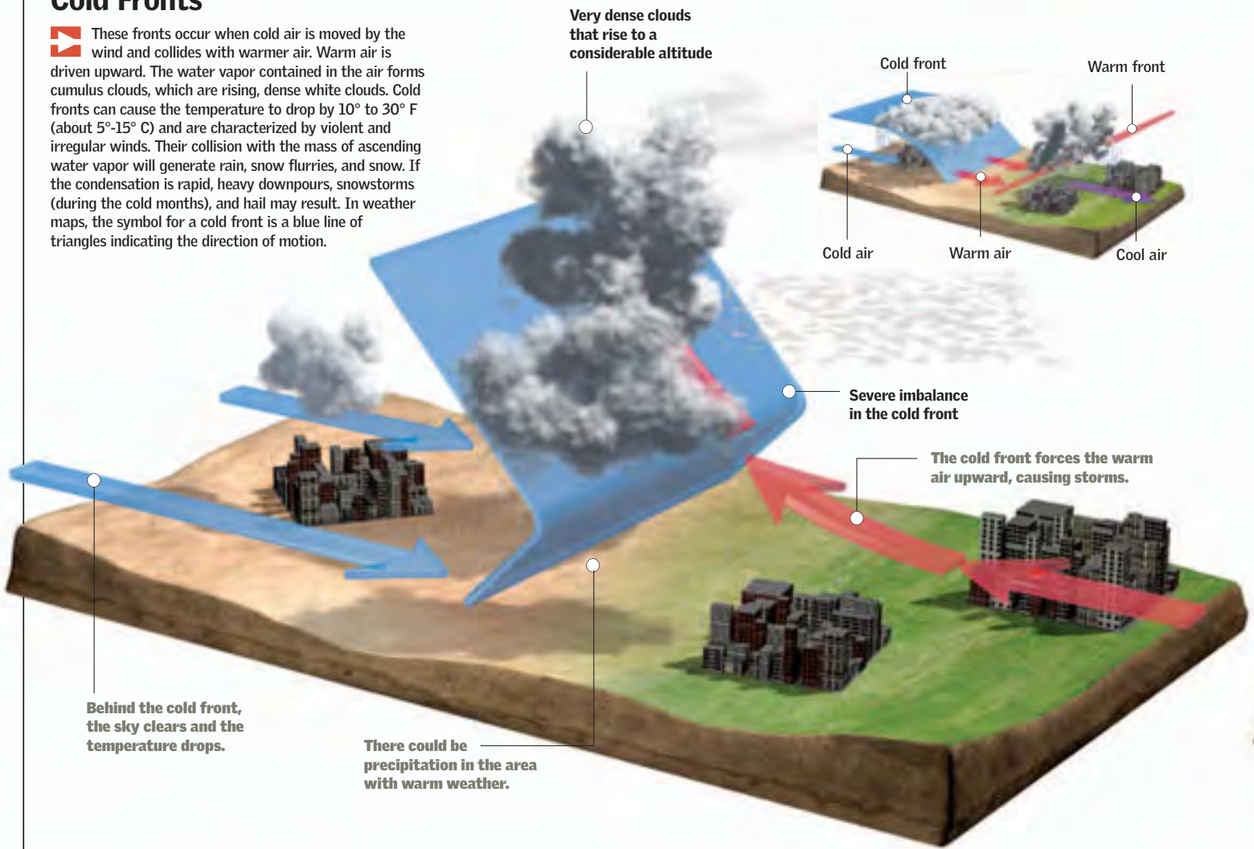


Collision

When two air masses with different temperatures and moisture content collide, they cause atmospheric disturbances. When the warm air rises, its cooling causes water vapor to condense and the formation of clouds and precipitation. A mass of warm and light air is always forced upward, while the colder and heavier air acts like a wedge. This cold-air wedge undercuts the warmer air mass and forces it to rise more rapidly. This effect can cause variable, sometimes stormy, weather.

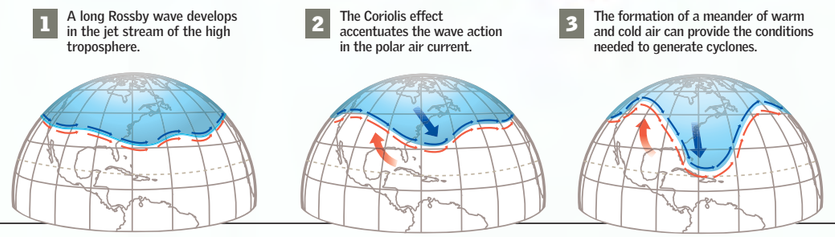
Cold Fronts

These fronts occur when cold air is moved by the wind and collides with warmer air. Warm air is driven upward. The water vapor contained in the air forms cumulus clouds, which are rising, dense white clouds. Cold fronts can cause the temperature to drop by 10° to 30° F (about 5°-15° C) and are characterized by violent and irregular winds. Their collision with the mass of ascending water vapor will generate rain, snow flurries, and snow. If the condensation is rapid, heavy downpours, snowstorms (during the cold months), and hail may result. In weather maps, the symbol for a cold front is a blue line of triangles indicating the direction of motion.



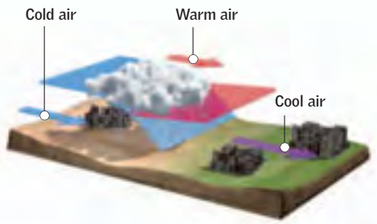
Rossby Waves

Large horizontal atmospheric waves that are associated with the polar-front jet stream. They may appear as large undulations in the path of the jet stream. The dynamics of the climatic system are affected by these waves because they promote the exchange of energy between the low and high latitudes and can even cause cyclones to form.



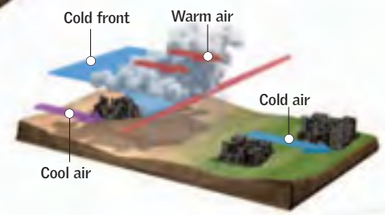
STATIONARY FRONTS

These fronts occur when there is no forward motion of warm or cold air—that is, both masses of air are stationary. This type of condition can last many days and produces only altocumulus clouds. The temperature also remains stable, and there is no wind except for some flow of air parallel to the line of the front. There could be some light precipitation.



OCCLUDED FRONTS

When the cold air replaces the cool air at the surface, with a warm air mass above, a cold occlusion is formed. A warm occlusion occurs when the cool air rises above the cold air. These fronts are associated with rain or snow, cumulus clouds, slight temperature fluctuations, and light winds.



Entire Continents

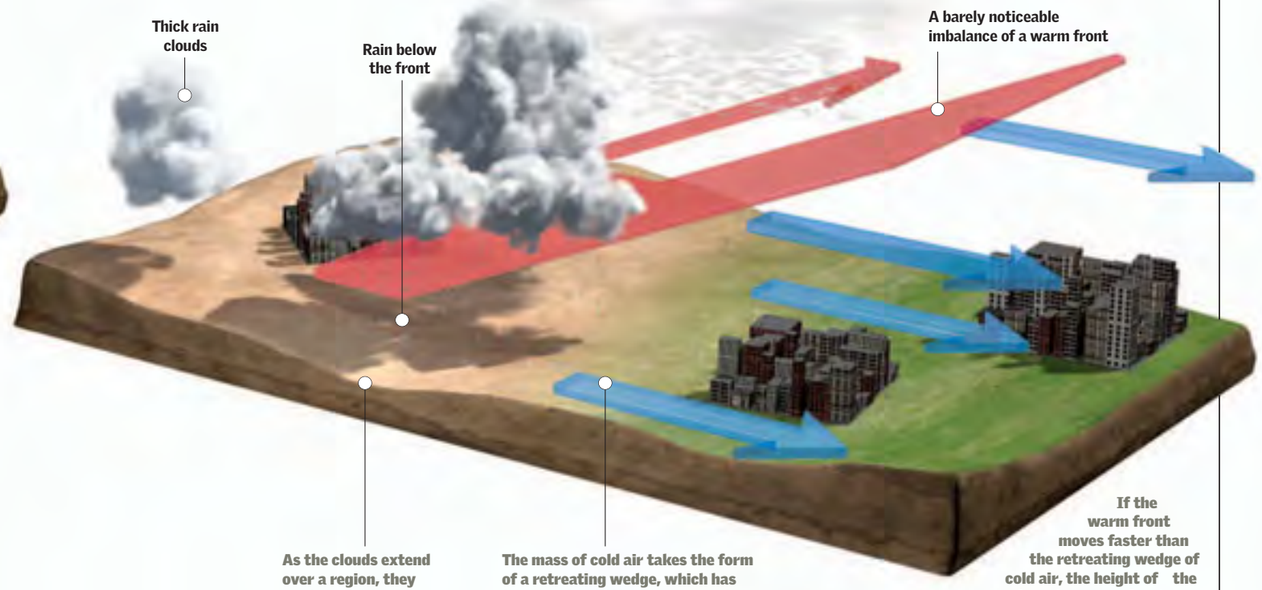
Fronts stretch over large geographic areas. In this case, a cold front causes storm perturbations in western Europe. But to the east, a warm front, extending over a wide area of Poland, brings light rain. These fronts can gain or lose force as they move over the Earth's surface depending on the global pressure system.

125 miles (200 km)

A warm front can be 125 miles (200 km) long. A cold front usually covers about 60 miles (100 km). In both cases, the altitude is roughly 0.6 mile (1 km).

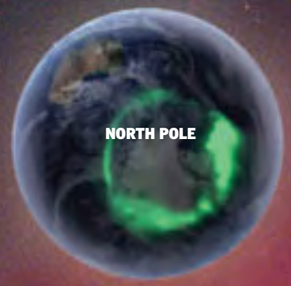
Warm Fronts

These are formed by the action of winds. A mass of warm air occupies a place formerly occupied by a mass of cold air. The speed of the cold air mass, which is heavier, decreases at ground level by friction, through contact with the ground. The warm front ascends and slides above the cold mass. This typically causes precipitation at ground level. Light rain, snow, or sleet are typically produced, with relatively light winds. The first indications of warm fronts are cirrus clouds, some 600 miles (1,000 km) in front of the advancing low pressure center. Next, layers of stratified clouds, such as the cirrostratus, altostratus, and nimbostratus, are formed while the pressure is decreasing.



Colors in the Sky

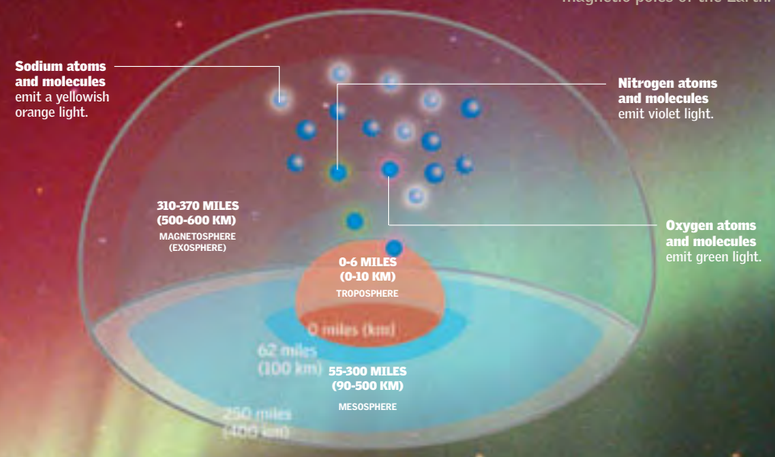
A natural spectacle of incomparable beauty, the auroras are produced around the magnetic poles of the Earth by the activity of the Sun. Solar wind acts on the magnetosphere, which is a part of the exosphere. In general, the greater the solar wind, the more prominent the aurora. Auroras consist of luminous patches and columns of various colors. Depending on whether they appear in the north or south, they are called aurora borealis or aurora australis. The aurora borealis can be seen in Alaska, Canada, and the Scandinavian countries.



A satellite image of the aurora borealis

How They Are Produced

The auroras are the result of the shock produced as ions coming from the Sun make contact with the magnetic field of the Earth. They appear in different colors depending on the altitude at which they are produced. Moreover, they demonstrate the function of the magnetosphere, which protects the planet against solar winds.



1 ELECTRONS COLLIDE WITH MOLECULES
The oxygen and nitrogen molecules receive the impact of the particles from the Sun. This occurs in the magnetosphere (exosphere).

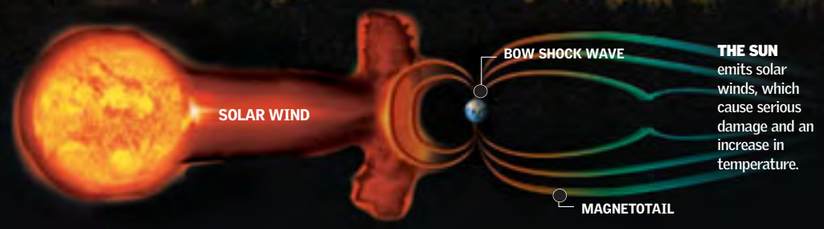
2 THEY BECOME EXCITED
After the shock, the atoms receive a significant additional energetic charge that will be released in the form of photons (light).

3 THEY GENERATE LIGHT
Depending on the altitude and the velocity where the shock is produced, the aurora displays different colors. Among the possibilities are violet, green, orange, and yellow.

620 miles (1,000 km)
is how long an aurora can be. From space it will look like a circle around one of the magnetic poles of the Earth.

Solar Winds

The Sun emits radiation, continuously and in all directions. This radiation occurs as a flow of charged particles or plasma, which consists mainly of electrons and protons. The plasma particles are guided by the magnetic field of the Sun and form the solar wind, which travels through space at some 275 miles per second (450 km/s). Particles from the solar wind arrive at the Earth within four or five days.



THE SUN
emits solar winds, which cause serious damage and an increase in temperature.

THE EARTH
The Earth's magnetosphere is responsible for protecting the planet from the deadly and harmful solar winds.

THE POLES
The auroras are more noticeable near the poles; they are called aurora borealis in the Northern Hemisphere and aurora australis in the Southern Hemisphere.

10-20 minutes
duration of the phenomenon

The amount of light emitted oscillates between 1 and 10 million megawatts, equivalent to the energy produced by 1,000 to 10,000 large electric power plants.

Surface Factors

VIETNAM, DECEMBER 1991
The intense monsoon rains caused severe flooding in vast regions of Cambodia, Vietnam, Laos, and Thailand.

LIVING WATER 20-21
OCEAN CURRENTS 22-23
AN OBSTACLE COURSE 24-25
THE LAND AND THE OCEAN 26-27
MONSOONS 28-29
GOOD FORTUNE AND CATASTROPHE 30-31
THE ARRIVAL OF EL NIÑO 32-33
THE EFFECTS OF EL NIÑO 34-35

Among meteorological phenomena, rain plays a very important role in the life of humans. Its scarcity causes serious problems, such as droughts, lack of food, and an increase in infant mortality. It is clear that an excess of water, caused by overabundant rain or the effects of gigantic waves, is also cause for alarm and concern. In Southwest Asia, there are frequent typhoons and torrential rains during which millions of people lose their houses and must be relocated to more secure areas; however, they still run the risk of catching contagious diseases such as malaria. The warm current of El Niño also affects the lives and the economy of millions of people. ●

Living Water

The water in the oceans, rivers, clouds, and rain is in constant motion. Surface water evaporates, water in the clouds precipitates, and this precipitation runs along and seeps into the Earth. Nonetheless, the total amount of water on the planet does not change. The circulation and conservation of water is driven by the hydrologic, or water, cycle. This cycle begins with evaporation of water from the Earth's surface. The water vapor humidifies as the air rises. The water vapor in the air cools and condenses onto solid particles as microdroplets. The microdroplets combine to form clouds. When the droplets become large enough, they begin to fall back to Earth, and, depending on the temperature of the atmosphere, they return to the ground as rain, snow, or hail. ●

WATER AVAILABILITY

(cubic feet [cu m] per capita/year)

- Less than 60,000 cu ft (1,700 cu m)
- 60,000-175,000 cu ft (1,700-5,000 cu m)
- More than 175,000 cu ft (5,000 cu m)

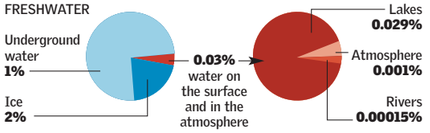
Access to potable water

- ▨ Less than 50% of the population

WHERE IT IS FOUND

A small percentage is freshwater; most of it is salt water.

FRESHWATER 3% **SALT WATER** 97%



1. EVAPORATION
Thanks to the effects of the Sun, ocean water is warmed and fills the air with water vapor. Evaporation from humid soil and vegetation increases humidity. The result is the formation of clouds.

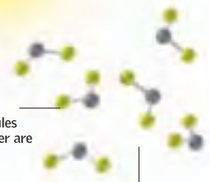
TRANSPIRATION
Perspiration is a natural process that regulates body temperature. When the body temperature rises, the sweat glands are stimulated, causing perspiration.

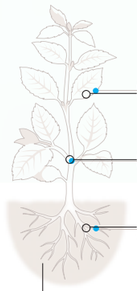
CONTRIBUTION OF LIVING BEINGS, ESPECIALLY PLANTS, TO **10%** THE WATER IN THE ATMOSPHERE

THE HUMAN BODY IS **65% WATER.**

GASEOUS STATE
The rays of the Sun increase the motion of atmospheric gases. The combination of heat and wind transforms liquid water into water vapor.

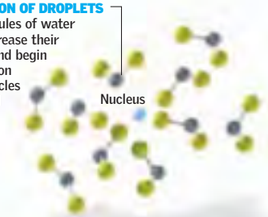
All the molecules of water are freed.





2. CONDENSATION
In order for water vapor to condense and form clouds, the air must contain condensation nuclei, which allow the molecules of water to form microdroplets. For condensation to occur, the water must be cooled.

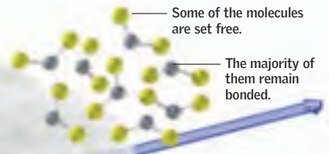
FORMATION OF DROPLETS
The molecules of water vapor decrease their mobility and begin to collect on solid particles suspended in the air.



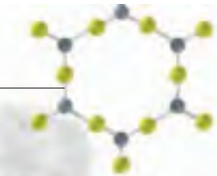
3. PRECIPITATION
The wind carries the clouds toward the continent. When the humid air cools, it condenses and falls as rain, snow, or hail.

72 cubic miles OF WATER FALL EACH DAY IN THE FORM OF PRECIPITATION.

LIQUID STATE
A rise in temperature increases the kinetic energy of the molecules, which breaks the hydrogen bonds.



SOLID STATE
The molecules have very little mobility because of the great number of bonds they establish with hydrogen atoms. They form snow crystals.



4. RUNOFF
Water in liquid form runs off the surface of the terrain via rivers and valleys. In climates that are not especially dry, this phenomenon is the principal geologic agent of erosion and transport. Runoff is reduced during times of drought.

5. UNDERGROUND CIRCULATION
There are two kinds, both of which are gravity driven. The first occurs in a shallow zone, in karstic rock such as limestone, and consists of a downward flow. The second occurs in aquifers, where interstitial water fills up the pores of a rock.

300 years
THE AVERAGE LENGTH OF TIME THAT A WATER MOLECULE REMAINS IN THE UNDERGROUND AQUIFERS

6. RETURN TO THE OCEAN
The waters return to the ocean, completing the cycle, which can take days for surface waters and years for underground waters.

340 cubic miles
OF WATER CIRCULATE IN THE TERRESTRIAL HYDROSPHERE.

Ocean Currents

Ocean water moves as waves, tides, and currents. There are two types of currents: surface and deep. The surface currents, caused by the wind, are great rivers in the ocean. They can be some 50 miles (80 km) wide. They have a profound effect on the world climate because the water warms up near the Equator, and currents transfer this heat to higher latitudes. Deep currents are caused by differences in water density.

THE INFLUENCE OF THE WINDS

TIDES AND THE CORIOLIS EFFECT

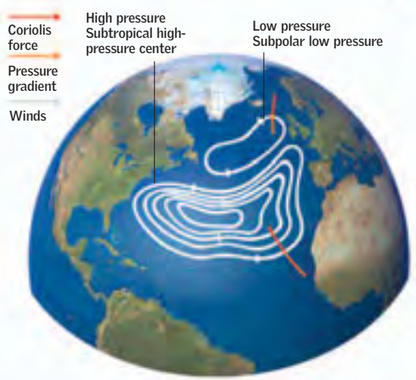
The Coriolis effect, which influences the direction of the winds, drives the displacement of marine currents.

Currents in the Northern Hemisphere travel in a clockwise direction.

In the Southern Hemisphere, the currents travel in a counterclockwise direction.

GEOSTROPHIC BALANCE

The deflection caused by the Coriolis effect on the currents is compensated for by pressure gradients between cyclonic and anticyclonic systems. This effect is called geostrophic balance.

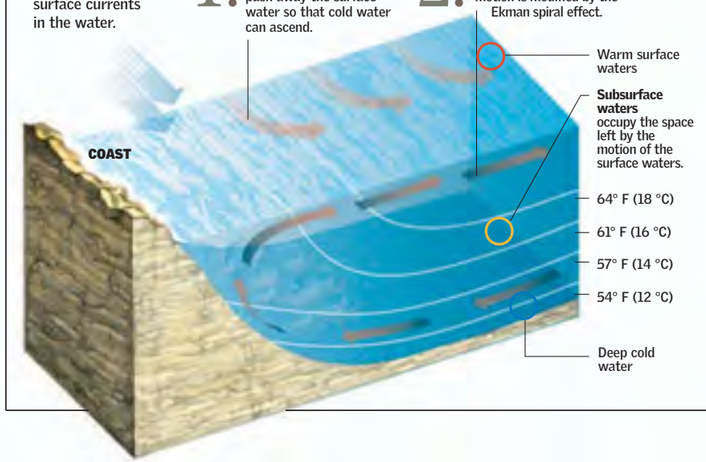


HOW CURRENTS ARE FORMED

Wind and solar energy produce surface currents in the water.

1. In the Southern Hemisphere, coastal winds push away the surface water so that cold water can ascend.

2. This slow ascent of deep water is called a surge. This motion is modified by the Ekman spiral effect.

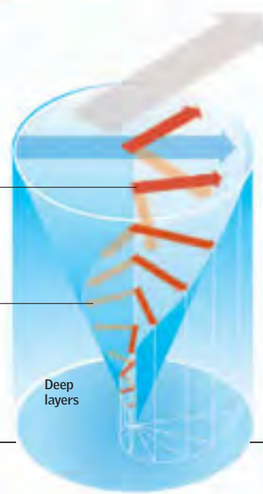


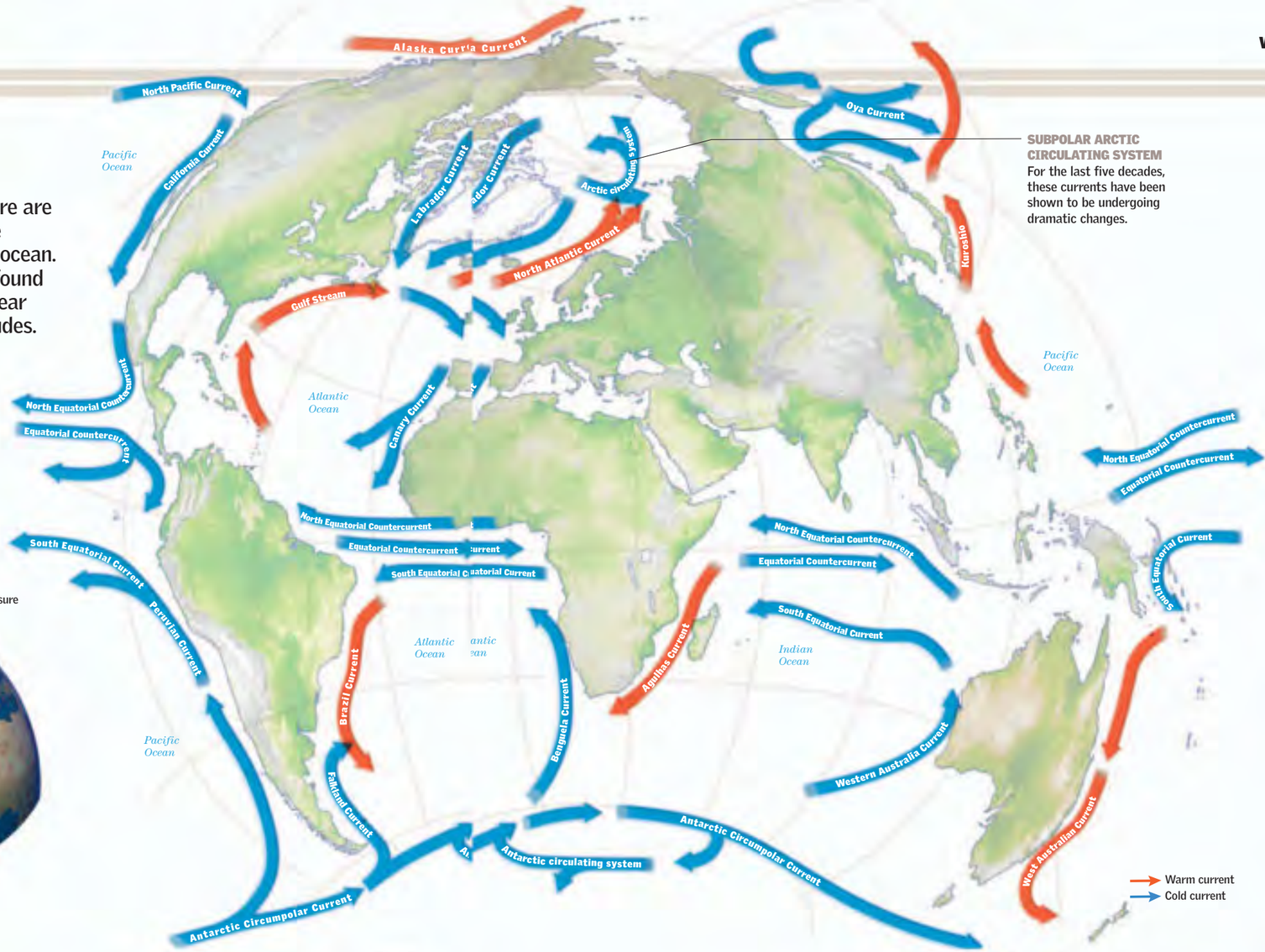
EKMAN SPIRAL

explains why the surface currents and deep currents are opposite in direction.

Wind energy is transferred to the water in **friction layers**. Thus, the velocity of the surface water increases more than that of the deep water.

The Coriolis effect causes the **direction of the currents** to deviate. The surface currents travel in the opposite direction of the deep currents.





SUBPOLAR ARCTIC CIRCULATING SYSTEM

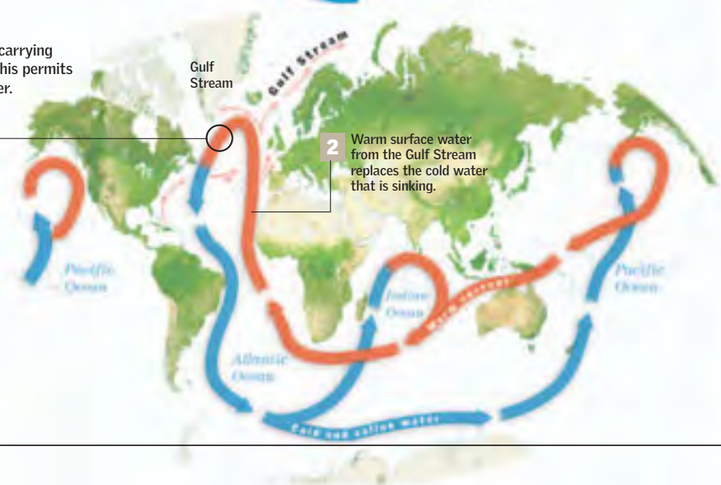
For the last five decades, these currents have been shown to be undergoing dramatic changes.

DEEP CURRENTS

have a vital function of carrying oxygen to deep water. This permits life to exist in deep water.

1 Near Greenland, the North Atlantic water **sinks**, and the **colder and more saline** water is pushed southward.

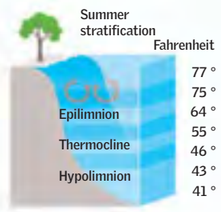
2 Warm surface water from the Gulf Stream replaces the cold water that is sinking.



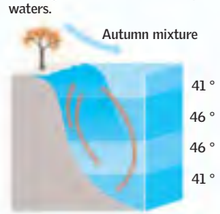
THE FOUR SEASONS OF A LAKE

Because of the physical properties of water, lakes and lagoons have a special seasonal circulation that ensures the survival of living creatures.

SUMMER
Stable summer temperatures prevent vertical circulation in the body of water of the lagoon.

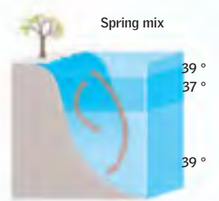


AUTUMN
Temperature decrease and temperature variations generate a mixing of the surface and deep waters.



WINTER
When the water reaches 39° F (4° C), its density increases. That is how strata of solid water on the surface and liquid water underneath are created.

SPRING
The characteristics of water once again initiate vertical circulation in the lake. Spring temperatures lead to this circulation.



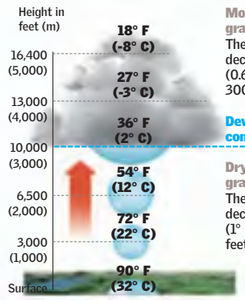
An Obstacle Course

The mountains are geographical features with a great influence on climate. Winds laden with moisture collide with these vertical obstacles and have to rise up their slopes to pass over them. During the ascent, the air discharges water in the form of precipitation on the windward sides, which are humid and have dense vegetation. The air that reaches the leeward slopes is dry, and the vegetation usually consists of sparse grazing land. ●

The Effect of the Andes Mountains

1. HUMID WINDS
In the mountains, the predominant winds are moisture-laden and blow in the direction of the coastal mountains.

2. ASCENT AND CONDENSATION
Condensation occurs when a mass of air cools until it reaches the saturation point (relative humidity 100 percent). The dew point rises when the air becomes saturated as it cools and the pressure is held constant.



Moist adiabatic gradient
The temperature decreases 1° F (0.6° C) for every 300 feet (100 m).

Dew point, or condensation point

Dry adiabatic gradient
The temperature declines 1.8° F (1° C) every 300 feet (100 m).

3. PRECIPITATION
A natural barrier forces the air to ascend and cool. The result is cloud formation and precipitation.

IN THE CLOUD

Temperature (in °F [°C])	Composition
-40 to -4 (-40 to -20)	Ice crystals
-4 to 14 (-20 to -10)	Supercooled water
14 to 32 (-10 to 0)	Microdroplets of water
Greater than 32 (0)	Drops of water

SNOW
Drops of super-cooled water combine to form ice crystals.

The crystals grow in size.

While they are falling, they combine with other crystals.

RAIN
The microdroplets increase in size and fall because of gravity.

When they fall, these drops collide with smaller ones.

Successive collisions increase the size of the drops.

4. DESCENDING WIND
A natural barrier forces the air to descend and warm up.

HIGH LEVEL OF POLLUTION IN SANTIAGO
Partly because it is the most urbanized and industrialized city of Chile, the capital, Santiago, faces serious pollution problems. In addition, it is located in a valley with characteristics that do not help disperse the pollution produced by vehicles and factories.

Santiago, Chile
Viña del Mar
Valparaíso
PACIFIC OCEAN
COASTAL MOUNTAIN RANGE
INTERMEDIATE DEPRESSION
CHILE
ARGENTINA

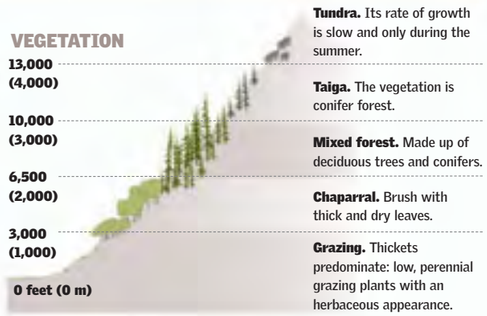
This drawing shows the coast and the Andes near Santiago, Chile, at Uspallata Pass.

ANDES MOUNTAIN RANGE
has altitudes greater than
19,700 feet (6,000 m).
It runs parallel to the Pacific Ocean, from Panama to southern Argentina. It is 4,500 miles (7,240 km) long and 150 miles (241 km) wide.

MAJOR MOUNTAIN RANGES

Mountain	Elevation
Everest	29,035 feet (8,850 m)
Aconcagua	22,834 feet (6,960 m)
Dhaulagiri	26,795 feet (8,167 m)
Makalu	27,766 feet (8,463 m)
Nanga Parbat	26,660 feet (8,126 m)
Kanchenjunga	28,169 feet (8,586 m)
Ojos del Salado	22,614 feet (6,893 m)
Kilimanjaro	19,340 feet (5,895 m)

VEGETATION



Tundra. Its rate of growth is slow and only during the summer.

Taiga. The vegetation is conifer forest.

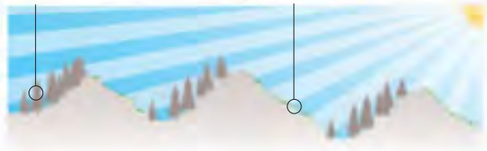
Mixed forest. Made up of deciduous trees and conifers.

Chaparral. Brush with thick and dry leaves.

Grazing. Thickets predominate: low, perennial grazing plants with an herbaceous appearance.

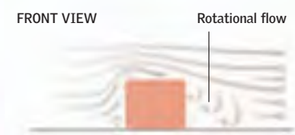
Western slopes
receive most of the moisture, which leads to the growth of pine and other trees of coastal mountain ranges.

Eastern slopes
The rays of the Sun fall directly upon these areas, making them more arid. There is little or no vegetation.



HOW OBSTACLES WORK

Obstacles, such as buildings, trees, and rock formations, decrease the velocity of the wind significantly and often create turbulence around them.



TYPES OF OROGRAPHICAL EFFECTS

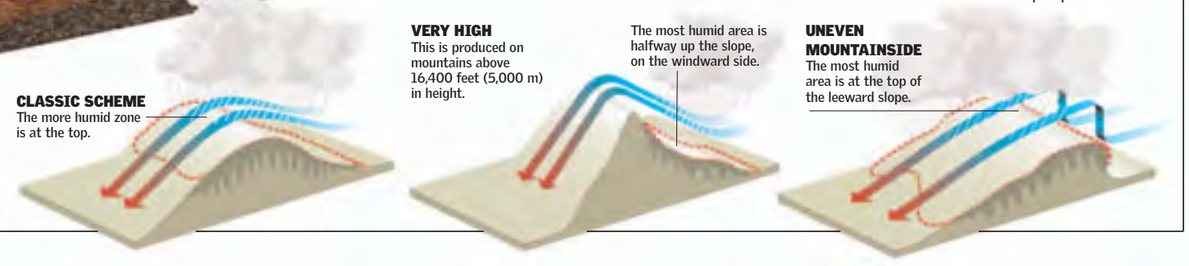
DRY Winds
HUMIDS Winds
Area affected by precipitation

CLASSIC SCHEME
The more humid zone is at the top.

VERY HIGH
This is produced on mountains above 16,400 feet (5,000 m) in height.

The most humid area is halfway up the slope, on the windward side.

UNEVEN MOUNTAINSIDE
The most humid area is at the top of the leeward slope.



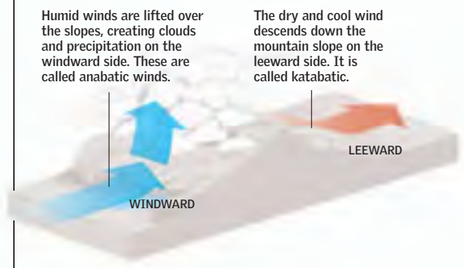
The Land and the Ocean

Temperature distribution and, above all, temperature differences very much depend on the distribution of land and water surface. Differences in specific heat moderate the temperatures of regions close to great masses of water. Water absorbs heat and releases it more slowly than the land does, which is why a body of water can heat or cool the environment. Its influence is unmistakable. Moreover, these differences between the land and the sea are the cause of the coastal winds. In clear weather, the land heats up during the day, which causes the air to rise rapidly and form a low-pressure zone. This zone draws marine breezes.

MOUNTAIN WINDS

Chinook WINDS

These winds are dry and warm, sometimes quite hot, occurring in various places of the world. In the western United States, they are called chinooks and are capable of making snow disappear within minutes.

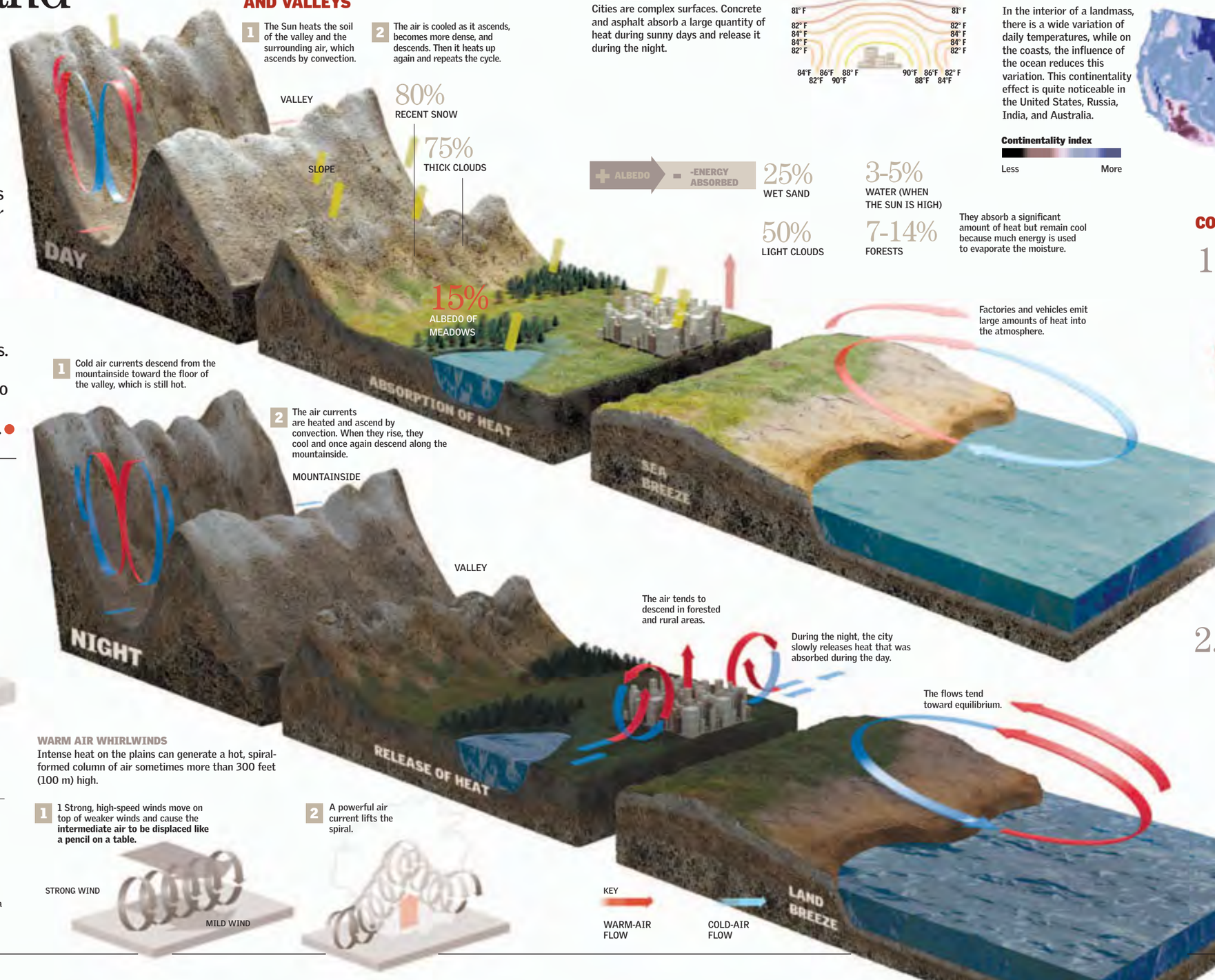


Winds	Characteristics	Location
Autan wind	Dry and mild	Southwestern France
Berg	Dry and warm	South Africa
Bora	Dry and cold	Northeastern Italy
Brickfielder	Dry and hot	Australia
Buran	Dry and cold	Mongolia
Harmattan	Dry and cool	North Africa
Levant	Humid and mild	Mediterranean region
Mistral	Dry and cold	Rhône valley
Santa Ana	Dry and hot	Southern California
Sirocco	Dry and hot	Southern Europe and North Africa
Tramontana	Dry and cold	Northeast Spain
Zonda	Dry and mild	Western Argentina

WINDS OF THE MOUNTAINS AND VALLEYS

1 The Sun heats the soil of the valley and the surrounding air, which ascends by convection.

2 The air is cooled as it ascends, becomes more dense, and descends. Then it heats up again and repeats the cycle.

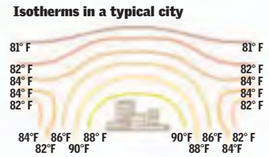


WARM AIR WHIRLWINDS

Intense heat on the plains can generate a hot, spiral-formed column of air sometimes more than 300 feet (100 m) high.

HEAT ISLANDS

Cities are complex surfaces. Concrete and asphalt absorb a large quantity of heat during sunny days and release it during the night.



25% WET SAND

3-5% WATER (WHEN THE SUN IS HIGH)

50% LIGHT CLOUDS

7-14% FORESTS

They absorb a significant amount of heat but remain cool because much energy is used to evaporate the moisture.

CONTINENTALITY

In the interior of a landmass, there is a wide variation of daily temperatures, while on the coasts, the influence of the ocean reduces this variation. This continentality effect is quite noticeable in the United States, Russia, India, and Australia.

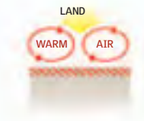
Continentality index

Less — More

Daily variation of temperatures in the United States

COASTAL BREEZES

1. **ON THE LAND**
During the day, the land heats up more rapidly than the ocean. The warm air rises and is replaced by cooler air coming from the sea.



Because it is opaque, the heat stays in the **surface layers**, which are heated and cooled rapidly.

IN THE OCEAN
From the coast, the ocean receives air that loses its heat near the water. As a result, the colder air descends toward the sea.

The heat penetrates into **deeper layers** thanks to the transparency of the water. A part of the heat is lost in evaporation of the water.

2. **ON THE LAND**
During the evening, the land radiates away its heat more rapidly than the water. The difference in pressure generated replaces the cold air of the coast with warm air.

When night falls, the land, which was hot, **cools rapidly.**

IN THE OCEAN
The loss of heat from the water is slower.

When night falls, the water is **lukewarm** (barely a degree more than the land).

Monsoons

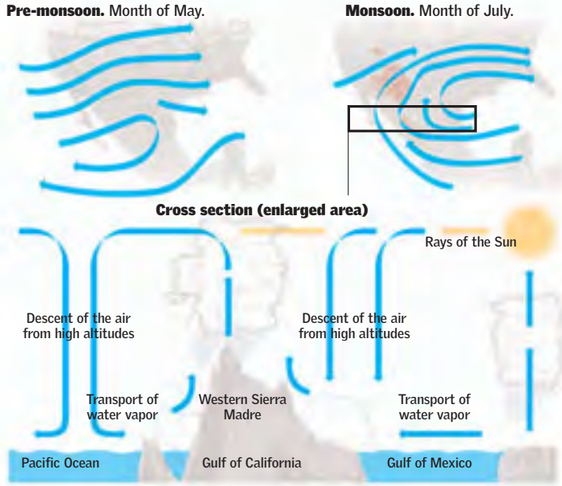
The strong humid winds that usually affect the tropical zone are called monsoons, an Arabic word meaning "seasonal winds." During summer in the Northern Hemisphere, they blow across Southeast Asia, especially the Indian peninsula. Conditions change in the winter, and the winds reverse and shift toward the northern regions of Australia. This phenomenon, which is also frequent in continental areas of the United States, is part of an annual cycle that, as a result of its intensity and its consequences, affects the lives of many people.

AREAS AFFECTED BY MONSOONS

This phenomenon affects the climates in low latitudes, from West Africa to the western Pacific. In the summer, the monsoon causes the rains in the Amazon region and in northern Argentina. There in the winter rain is usually scarce.

Predominant direction of the winds during the month of July

THE MONSOON OF NORTH AMERICA



How monsoons are created in India

End of the monsoon · Beginning of the monsoon · Cold and dry winds · Cold and humid winds · Cyclone (low pressure) · Anticyclone (high pressure)

1 THE CONTINENT COOLS

After the summer monsoon, the rains stop and temperatures in Central and South Asia begin to drop. Winter begins in the Northern Hemisphere.

Northern Hemisphere
It is winter. The rays of the Sun are oblique, traveling a longer distance through the atmosphere to reach the Earth's surface. Thus they are spread over a larger surface, so the average temperature is lower than in the Southern Hemisphere.

Southern Hemisphere
It is summer. The rays of the Sun strike the surface at a right angle; they are concentrated in a smaller area, so the temperature on average is higher than in the Northern Hemisphere.

2 FROM THE CONTINENT TO THE OCEAN

The masses of cold and dry air that predominate on the continent are displaced toward the ocean, whose waters are relatively warmer.

3 OCEAN STORMS

A cyclone located in the ocean draws the cold winds from the continent and lifts the somewhat warmer and more humid air, which returns toward the continent via the upper layers of the atmosphere.

INTERTROPICAL INFLUENCE

The circulation of the atmosphere between the tropics influences the formation of monsoon winds. The trade winds that blow toward the Equator from the subtropical zones are pushed by the Hadley cells and deflected in their course by the Coriolis effect. Winds in the tropics occur within a band of low pressure around the Earth called the Intertropical Convergence Zone (ITCZ). When this zone is seasonally displaced in the warm months of the Northern Hemisphere toward the north, a summer monsoon occurs.

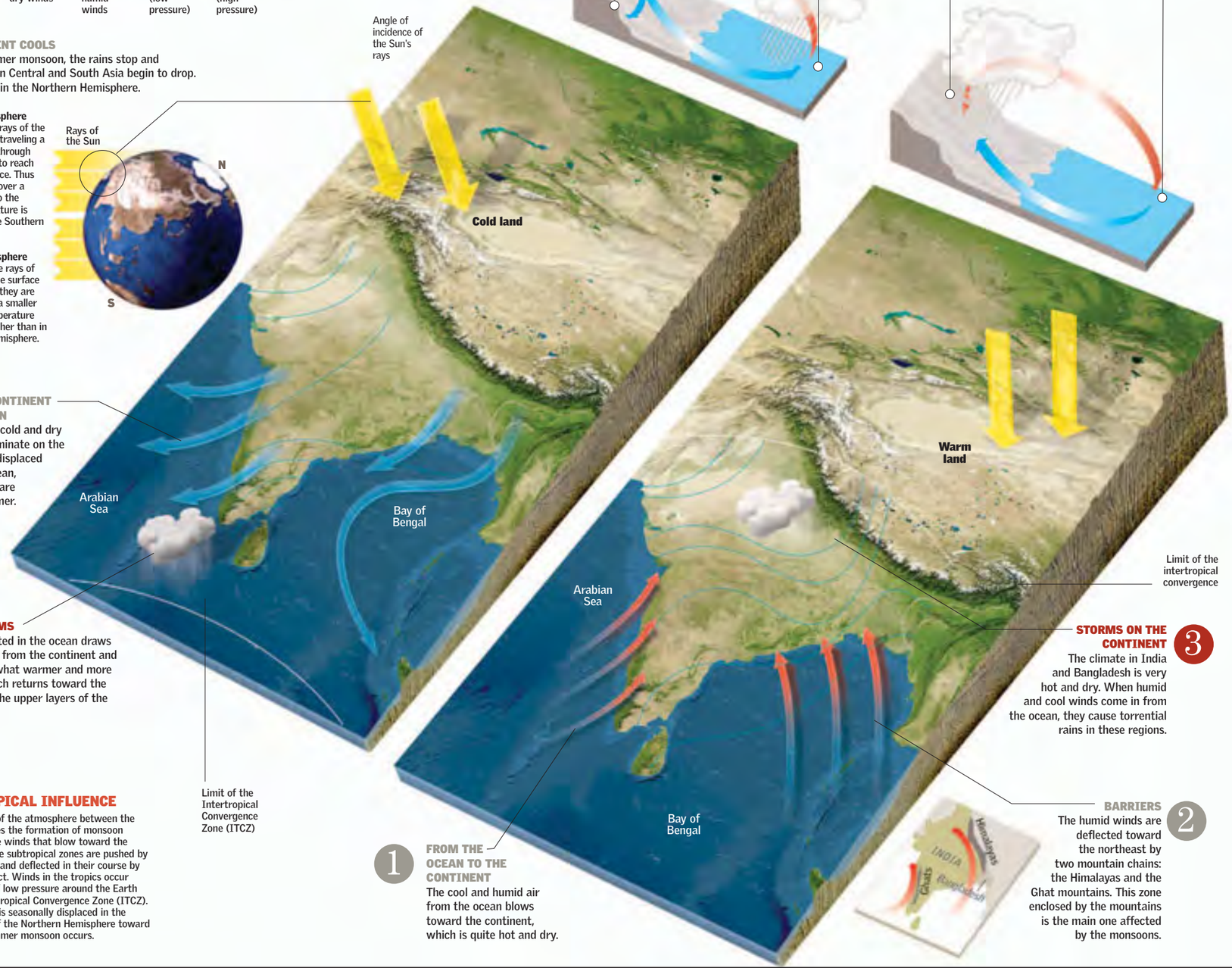
THERMAL DIFFERENCE BETWEEN THE LAND AND THE OCEAN

The land is cold, so near the ground the breeze blows toward the ocean.

The sea is a little warmer than the land; therefore, the humid air rises. The cool air colliding with it causes clouds and rain.

The Earth is hot, and therefore the air rises and is replaced in the lower layers by cool breezes that blow in from the sea. The meeting of the two breezes causes clouds and rain on the continent.

The sea is cold because the rays of the Sun heat up the water more slowly than the land. The cool air from the ocean blows toward the coast, toward areas that are warmer.



1 FROM THE OCEAN TO THE CONTINENT

The cool and humid air from the ocean blows toward the continent, which is quite hot and dry.

2 BARRIERS

The humid winds are deflected toward the northeast by two mountain chains: the Himalayas and the Ghat mountains. This zone enclosed by the mountains is the main one affected by the monsoons.

3 STORMS ON THE CONTINENT

The climate in India and Bangladesh is very hot and dry. When humid and cool winds come in from the ocean, they cause torrential rains in these regions.

Good Fortune and Catastrophe

The monsoons are a climatic phenomenon governing the life and the economy of one of the most densely populated regions of the planet, especially India. The arrival of the intense rains is celebrated as the end of a season that might have been extremely dry, but it is also feared. The flooding at times devastates agriculture and housing. The damage is even greater because of the large population of the region. Therefore, anticipating disaster and taking precautions, such as evacuating areas prone to flooding, are part of the organization of agricultural activity, which thrives in periods of heavy rains, even in fields that are flooded.

In June 2006

The tragic outcome of the monsoon in South Asia

~49
DEATHS
on June 16, 2006

INDIA AND BANGLADESH
Total population
1.25 billion

~1 million
PEOPLE STRANDED BY STORMS IN BANGLADESH

~212 **DEATHS IN INDIA**
During the month of June 2006. Most of them were electrocuted by lightning during electrical storms.

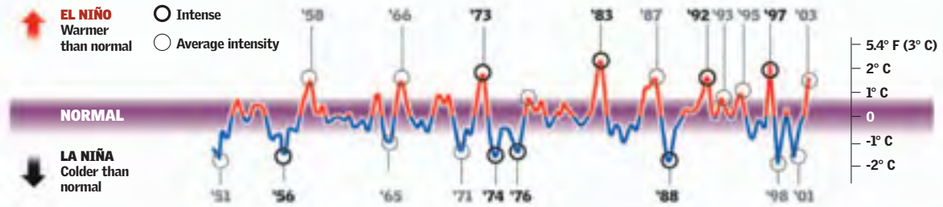
UNDERWATER HARVEST
The mud increases the fertility of the soil, which compensates for the losses. The accumulation of humid sand is later used in the dry season. Rice is a grain that grows in fields that are underwater.

OVERFLOWING RIVERS
The valley that connects the Ganges with the Brahmaputra in Bangladesh is the most afflicted by floods caused by these rains. The rains destroy harvests and property.

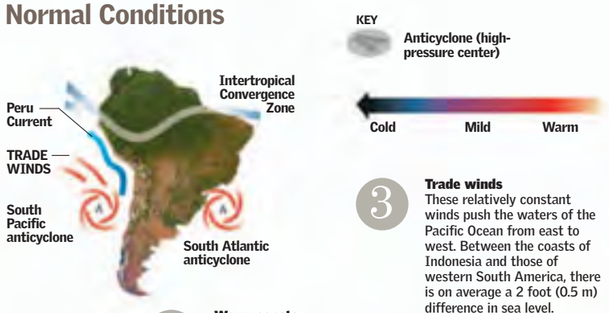
The Arrival of El Niño

The hydrosphere and the atmosphere interact and establish a dynamic thermal equilibrium between the water and the air. If this balance is altered, unusual climatic phenomena occur between the coasts of Peru and Southeast Asia. For example, the phenomenon El Niño or, less frequently, another phenomenon called La Niña are responsible for atypical droughts and floods that every two to seven years affect the routine life of people living on these Pacific Ocean coasts.

SURFACE TEMPERATURE OF THE OCEAN
The graphic shows the temperature variations caused by the Southern Oscillation in the water along the coast of Peru. This graphic illustrates the alternation of the El Niño and La Niña phenomena over the last 50 years.



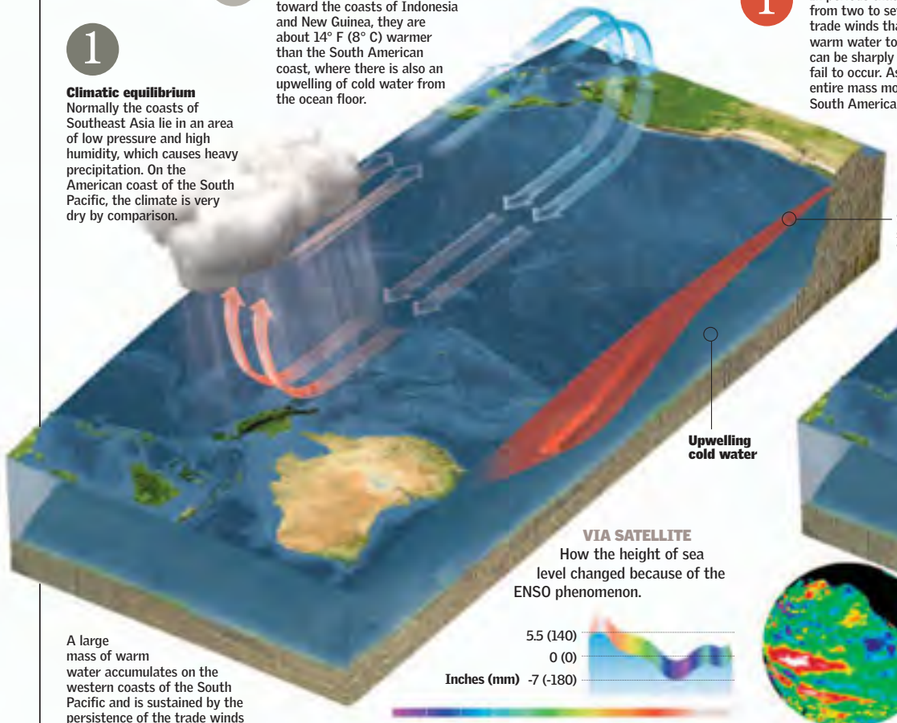
Normal Conditions



3 Trade winds
These relatively constant winds push the waters of the Pacific Ocean from east to west. Between the coasts of Indonesia and those of western South America, there is on average a 2 foot (0.5 m) difference in sea level.

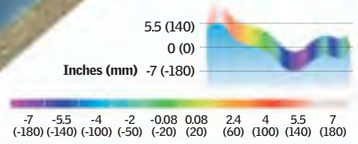
2 Warm coasts
Because great masses of warm water permanently flow toward the coasts of Indonesia and New Guinea, they are about 14° F (8° C) warmer than the South American coast, where there is also an upwelling of cold water from the ocean floor.

1 Climatic equilibrium
Normally the coasts of Southeast Asia lie in an area of low pressure and high humidity, which causes heavy precipitation. On the American coast of the South Pacific, the climate is very dry by comparison.



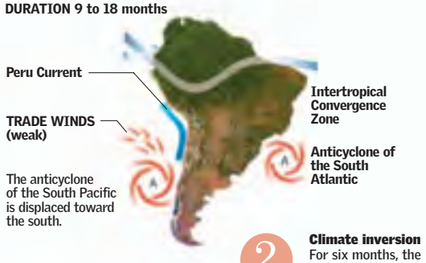
A large mass of warm water accumulates on the western coasts of the South Pacific and is sustained by the persistence of the trade winds at the ocean surface.

VIA SATELLITE
How the height of sea level changed because of the ENSO phenomenon.



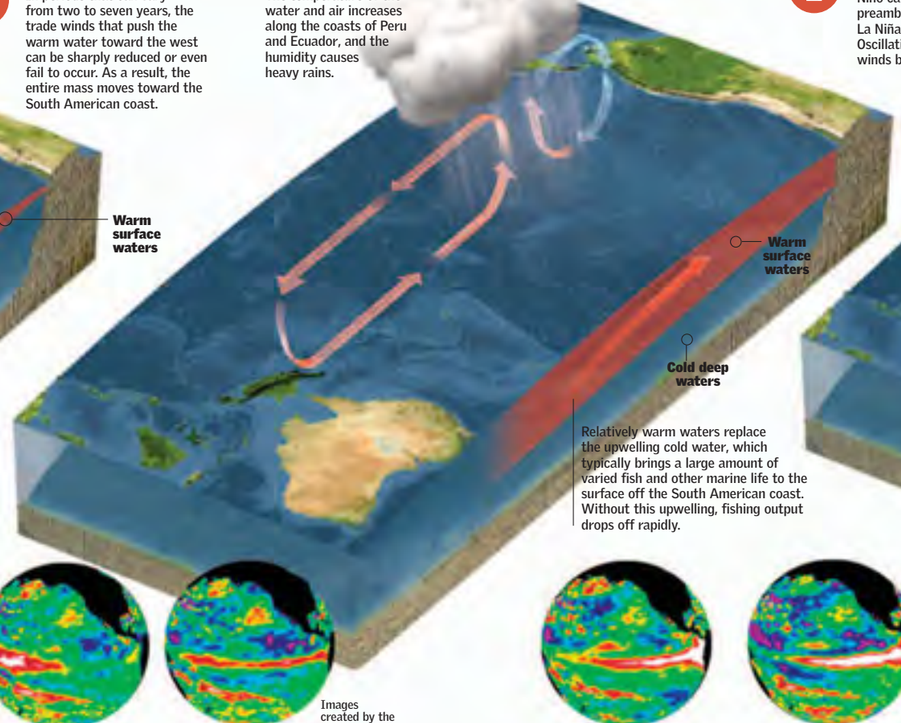
El Niño (the warm phase of El Niño/Southern Oscillation [ENSO])

DURATION 9 to 18 months

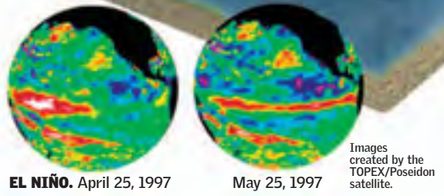


2 Climate inversion
For six months, the normal climatic conditions are reversed. The temperature of the water and air increases along the coasts of Peru and Ecuador, and the humidity causes heavy rains.

1 Without trade winds
In periods that can vary from two to seven years, the trade winds that push the warm water toward the west can be sharply reduced or even fail to occur. As a result, the entire mass moves toward the South American coast.



Relatively warm waters replace the upwelling cold water, which typically brings a large amount of varied fish and other marine life to the surface off the South American coast. Without this upwelling, fishing output drops off rapidly.



EL NIÑO. April 25, 1997 — May 25, 1997

Images created by the TOPEX/Poseidon satellite.

3 El Niño makes itself felt.
Southeast Asia suffers a great drought, an increase of pressure, and a decrease in temperature. On the South American coast, strong winds and storms occur in zones that are usually dry; there is flooding and changes in the flora and fauna.

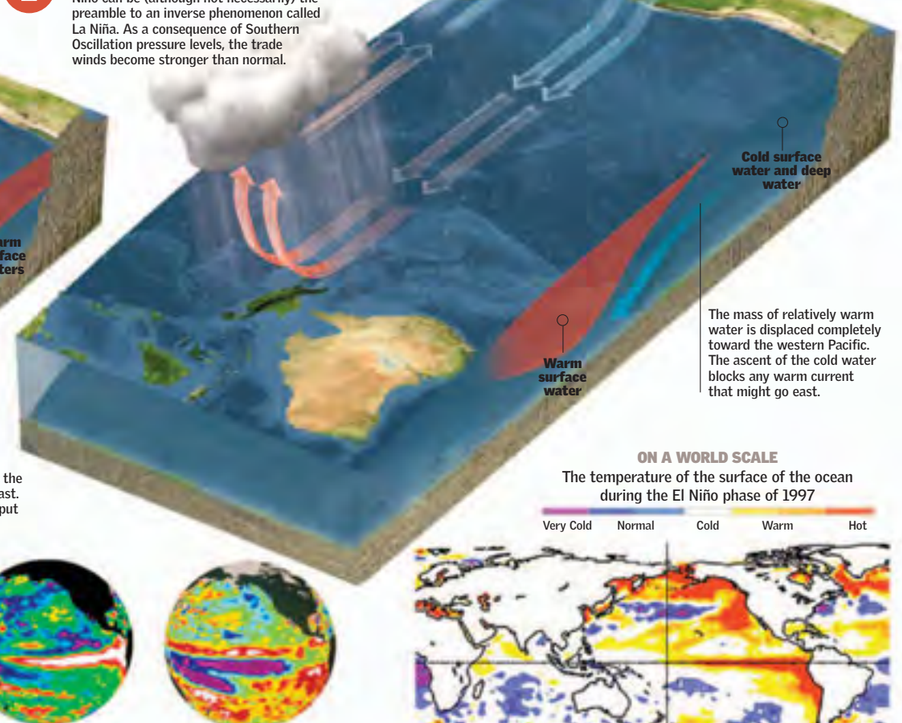
La Niña (cold ENSO)

DURATION: 9 to 18 months
FREQUENCY: Every 2 to 7 years

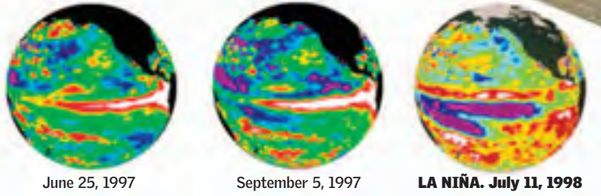
2 A cold current
The total disruption of the masses of warm water off the west coast of South America also generates colder surface temperatures than normal along with high pressure and decreased humidity.

3 Severe drought
The effects of La Niña are less severe than those of El Niño. Also, the shorter its duration, the more intense it is. It typically begins about halfway through the year and intensifies at the end of the year before weakening around the beginning of the new year. In the Caribbean, La Niña causes an increase in humidity.

1 Overcompensation
The return of normal conditions after El Niño can be (although not necessarily) the preamble to an inverse phenomenon called La Niña. As a consequence of Southern Oscillation pressure levels, the trade winds become stronger than normal.

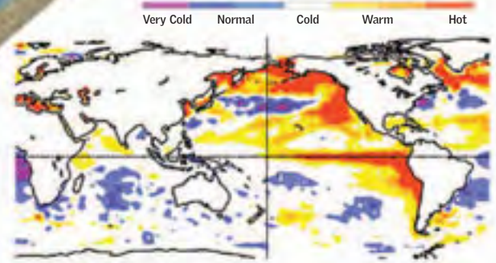


The mass of relatively warm water is displaced completely toward the western Pacific. The ascent of the cold water blocks any warm current that might go east.



June 25, 1997 — September 5, 1997 — **LA NIÑA. July 11, 1998**

ON A WORLD SCALE
The temperature of the surface of the ocean during the El Niño phase of 1997

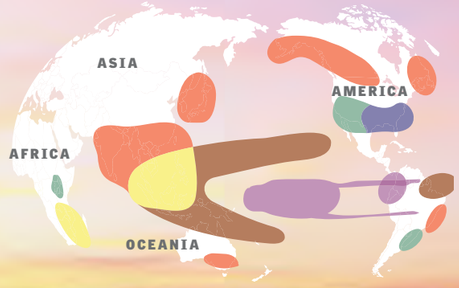


The Effects of El Niño

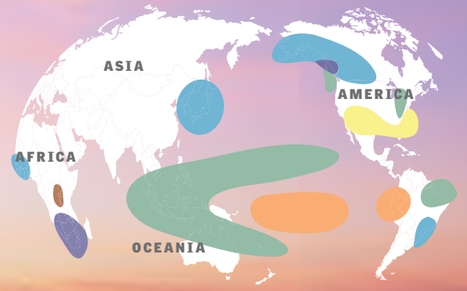
The natural warm phenomenon known as El Niño alters the temperature of the water within the east central zone of the Pacific Ocean along the coasts of Ecuador and Peru. Farmers and fishermen are negatively affected by these changes in temperature and the modification of marine currents. The nutrients normally present in the ocean decrease or disappear from along the coast because of the increase in temperature. As the entire food chain deteriorates, other species also suffer the effects and disappear from the ocean. In contrast, tropical marine species that live in warmer waters can flourish. The phenomenon affects the weather and climate of the entire world. It tends to cause flooding, food shortages, droughts, and fires in various locations.

Areas Affected

EL NIÑO from December to February



LA NIÑA from June to August



KEY
- Humid
- Cold
- Cold Humid
- Warm Humid
- Warm Humid
- Dry
- Dry and cold
- Dry and warm

FLOODING
Abnormal flooding caused by El Niño in the desert regions of Chile and the later evaporation of water leave behind hexagonal deposits of potassium nitrate.

ATACAMA, CHILE
Laguna Blanca Salt Marsh
Latitude 22° 54´ S
Longitude 68° 12´ W

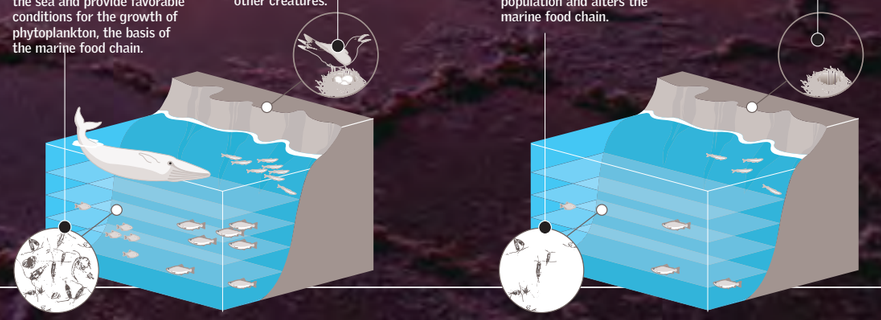
Surface area	**1,200 square miles (3,000 sq km)**
Cause	**Floods caused by El Niño anomalies**
Year	**1999**

Normal conditions
Cold waters, rich in nutrients, ascend from the bottom of the sea and provide favorable conditions for the growth of phytoplankton, the basis of the marine food chain.

The phytoplankton promote the normal development of microorganisms, fish, and other creatures.

During El Niño,
the scarcity of cold water debilitates the phytoplankton population and alters the marine food chain.

Various marine species die off for lack of food or must migrate to other zones.



Meteorological Phenomena

HURRICANE ALERT
This image of Hurricane Elena, captured by the Space Shuttle on September 1, 1985, allowed meteorologists to evaluate its scope before it reached the Gulf of Mexico.

CAPRICIOUS FORMS 38-39
THE RAIN ANNOUNCES ITS COMING 40-43
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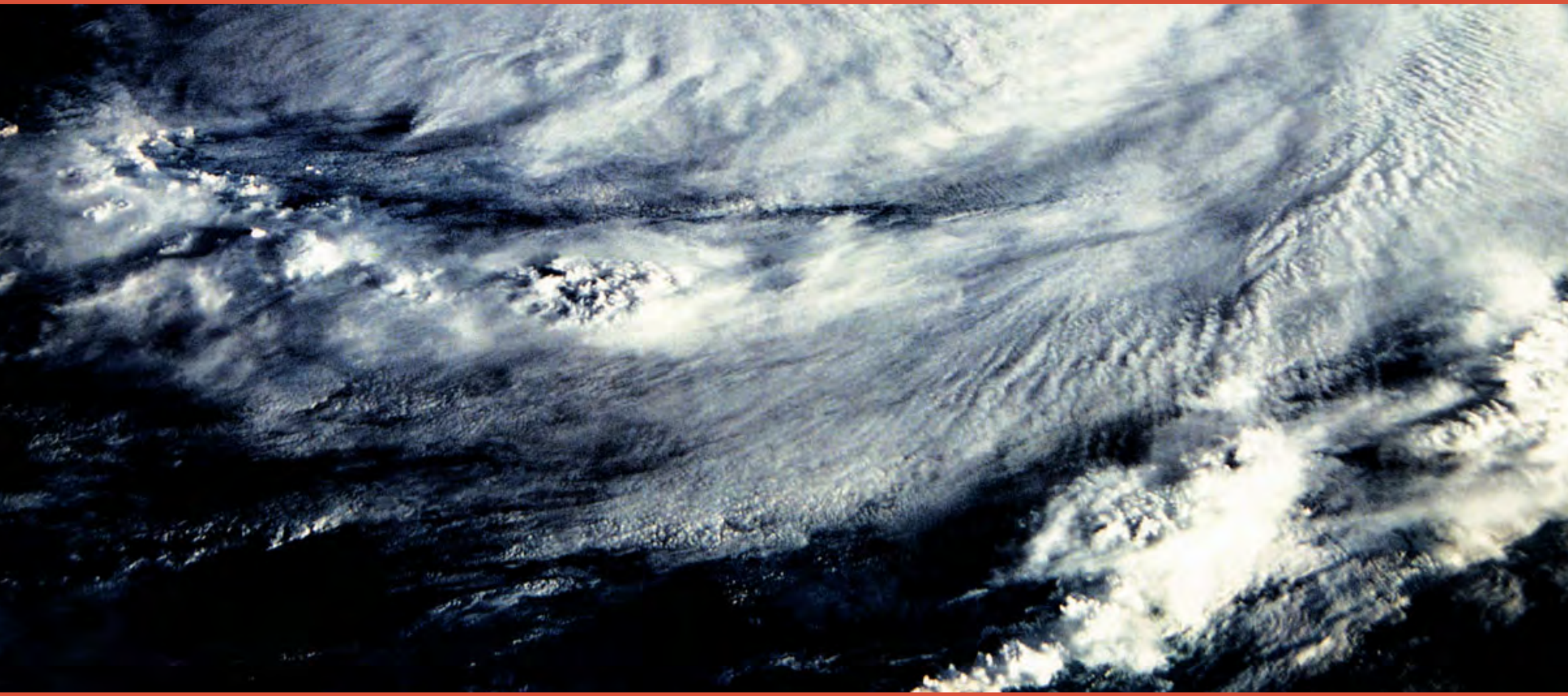


Tropical cyclones (called hurricanes, typhoons, or cyclones in different parts of the world) cause serious problems and often destroy everything in their path. They uproot trees, damage buildings, devastate land under cultivation, and cause deaths. The Gulf of Mexico is one of the areas of the planet continually affected by hurricanes. For this reason, the government authorities organize preparedness exercises so that the population knows what to do. To understand how hurricanes function and improve forecasts, investigators require detailed information from the heart of the storm. The use of artificial satellites that send clear pictures has contributed greatly to detecting and tracking strong winds, preventing many disasters. ●

Capricious Forms

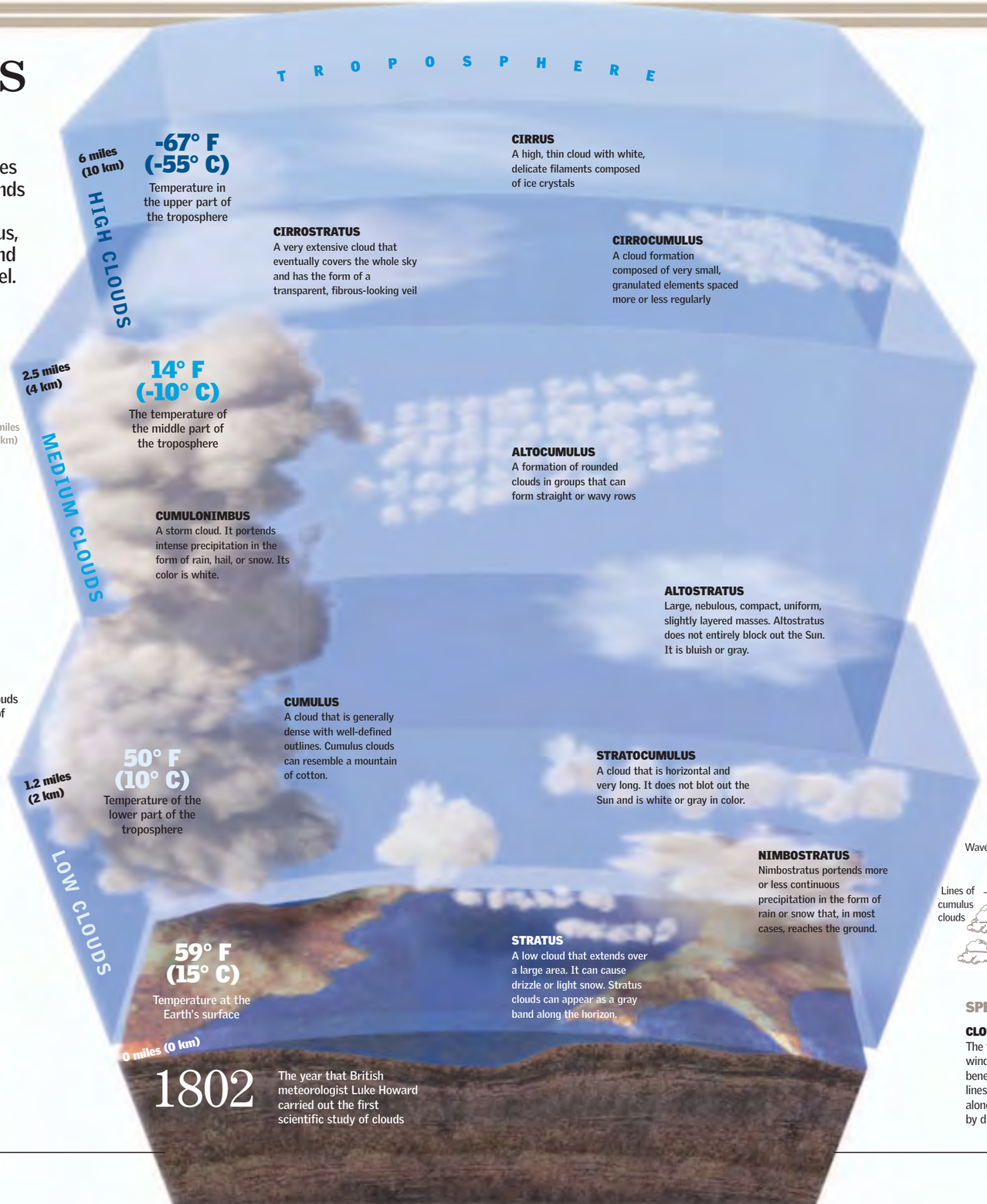
Clouds are masses of large drops of water and ice crystals. They form because the water vapor contained in the air condenses or freezes as it rises through the troposphere. How the clouds develop depends on the altitude and the velocity of the rising air. Cloud shapes are divided into three basic types: cirrus, cumulus, and stratus. They are also classified as high, medium, and low depending on the altitude they reach above sea level. They are of meteorological interest because they indicate the behavior of the atmosphere. ●

TYPES OF CLOUDS

NAME	MEANING
CIRRUS	FILAMENT
CUMULUS	AGGLOMERATION
STRATUS	BLANKET
NIMBUS	RAIN

Troposphere

The layer closest to the Earth and in which meteorological phenomena occur, including the formation of clouds



1802 The year that British meteorologist Luke Howard carried out the first scientific study of clouds

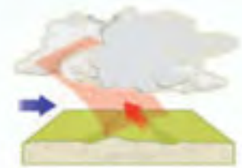
HOW THEY ARE FORMED

Clouds are formed when the rising air cools to the point where it cannot hold the water vapor it contains. In such a circumstance, the air is said to be saturated, and the excess water vapor condenses. Cumulonimbus clouds are storm clouds that can reach a height of 43,000 feet (13,000 m) and contain more than 150,000 tons of water.

Convection
The heat of the Sun warms the air near the ground, and because it is less dense than the surrounding air, it rises.

Convergence
When the air coming from one direction meets air from another direction, it is pushed upward.

Geographic elevation
When the air encounters mountains, it is forced to rise. This phenomenon explains why there are often clouds and rain over mountain peaks.



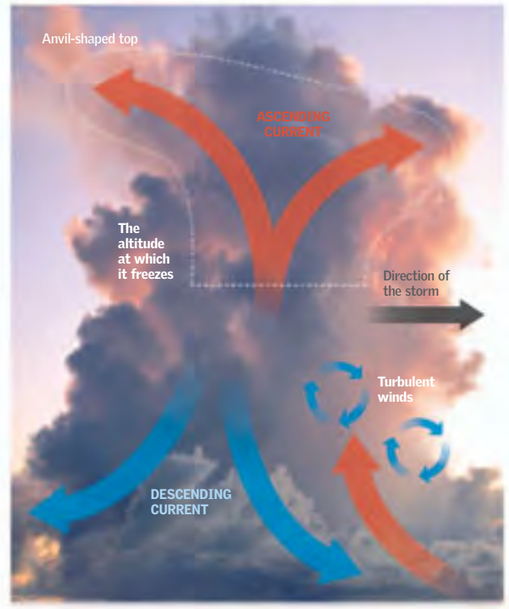
Presence of a front
When two masses of air with different temperatures meet at a front, the warm air rises and clouds are formed.

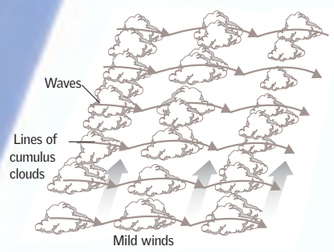
The Inside

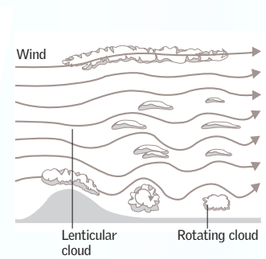
The altitude at which clouds are formed depends on the stability of the air and the humidity. The highest and coldest clouds have ice crystals. The lowest and warmest clouds have drops of water. There are also mixed clouds. There are 10 classes of clouds depending on their height above sea level. The highest clouds begin at a height of 2.5 miles (4 km). The mid-level begins at a height of 1.2 to 2.5 miles (2-4 km) and the lowest at 1.2 miles (2 km) high.

1.2 to 5 miles (2-8 km)
Thickness of a storm cloud

150,000 tons of water
can be contained in a storm cloud.







SPECIAL FORMATIONS

CLOUD STREETS
The form of the clouds depends on the winds and the topography of the terrain beneath them. Light winds usually produce lines of cumulus clouds positioned as if along streets. Such waves can be created by differences in surface heating.

LENTICULAR CLOUDS
Mountains usually create waves in the atmosphere on their lee side, and on the crest of each wave lenticular clouds are formed that are held in place by the waves. Rotating clouds are formed by turbulence near the surface.

The Rain Announces Its Coming

The air inside a cloud is in continuous motion. This process causes the drops of water or the crystals of ice that constitute the cloud to collide and join together. In the process, the drops and crystals become too big to be supported by air currents and they fall to the ground as different kinds of precipitation. A drop of rain has a diameter 100 times greater than a droplet in a cloud. The type of precipitation depends on whether the cloud contains drops of water, ice crystals, or both. Depending on the type of cloud and the temperature, the precipitation can be liquid water (rain) or solid (snow or hail).

1 CONDENSATION NUCLEI
Salt, dust, smoke, and pollen, among other particulates, serve as a surface on which water molecules, ascending by convection, can combine and form water droplets.

2 GROWTH
The smallest clouds adhere to one another to form larger clouds, increasing their size and height.

A Dilatation
The molecules of water are free–water vapor.

Water molecules
Hydrogen
Oxygen

B Condensation
The molecules group themselves around a condensation nucleus.

C Collision-Coalescence
Via this process, molecules collide and join together to form drops.

Sandstorm particulates
Forest fire particulates
Particulates from combustion in factories and vehicles
Volcanic particulates
Rock erosion particulates
Sea-salt particulates

3 MATURATION
Mature clouds have very strong ascending currents, leading to protuberances and rounded formations. Convection occurs.

4 miles (7 km)

-22° F (-30° C)

When the air cools, it descends and is then heated again, repeating the cycle.

0.02 inch (0.5 mm)

The air cools. The water vapor condenses and forms microdroplets of water.

0.6-1.2 miles (1-2 km)

LEVEL OF CONDENSATION

68° F (20° C)
The hot air rises.

0 miles (0 km)

4 RAIN
The upper part of the cloud spreads out like an anvil, and the rain falls from the lower cloud, producing descending currents.

6 miles (10 km)

Anvil-shaped

STORM CLOUD

Coalescence
The microdroplets continue to collide and form bigger drops.

Heavier drops fall onto a lower cloud as fine rain.

0.04 inch (1 mm)

0.07 inch (2 mm)

5 DISSIPATION
The descending currents are stronger than the ascending ones and interrupt the feeding air, causing the cloud to disintegrate..

Low, thin clouds contain tiny droplets of water and therefore produce rain.

0.2 inch (5 mm)

0.04 inch (1 mm)

When they begin to fall, the drops have a size of 0.02 inch (0.5 mm), which is reduced as they fall since they break apart.

26,875 trillion
molecules occupy 1 cubic millimeter under normal atmospheric conditions.

6 SNOW

Tiny ice crystals combine to form a hexagonal star, or snowflake. They form at -4° F (-20° C).

A HOW CRYSTALS ARE FORMED

The drop attaches itself to a nucleus or solid particle.

Drop

Condensation nucleus

Then the surface of the drop freezes.

Nucleus

Periphery

ICE CRYSTAL

3 miles (5 km)

-39° F (-39° C)

SNOWFLAKE

2 miles (3 km)

-9° F (-23° C)

B The ice crystals combine and form snowflakes.

C If the drops crystallize near the freezing level, they fall in the form of sleet.

0.6 mile (1 km)

19° F (-7° C)

ASCENDING WARM CURRENT

SLEET

SNOWFALL

Most snowflakes disintegrate before they reach the ground. They fall as snowflakes only when the air near the ground is very cold.

10 feet (3.11 m)

The record of annual snowfall
Mount Rainier, Washington. From February 19, 1971, to February 18, 1972.

TYPES OF CRYSTALS

Plate

Column

Dendrite

Needle clusters

No two snowflakes are identical to each other.

VARIED FORMS

Snow crystals can have a variety of shapes; most of them have six points, although some have three or 12, and they have hexagonal symmetry in a plane. They can also be cubic crystals, but these form under conditions of extremely low temperature in the highest regions of the troposphere.

Most have **six points**.

The flakes measure between **0.04 and 0.8 inch (1 and 20 mm)**.

A Vertical air currents cause the microdroplets to ascend and descend within the cloud.

B The droplets freeze, and each time they are carried upward in the cloud, they acquire a new layer of ice. This process, called accretion, increases the size of the hailstone.

Very small hail (0.2 inch [5 mm] or less in diameter) is called snow pellets.

C When the hailstones are too heavy to be supported by the ascending air currents, they fall to the ground.

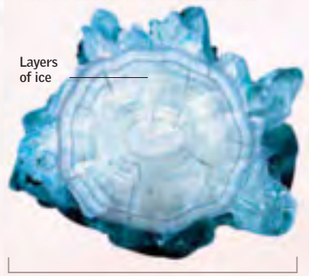
WARM ASCENDING CURRENT

A cloud with a greenish tinge or rain with a whitish color can portend a hailstorm.

7 HAIL

Precipitation in the form of solid lumps of ice. Hail is produced inside storm clouds in which frozen droplets grow in size as they rise and fall within the cloud.

CROSS SECTION OF A HAILSTONE



0.2 to 2 inches (5 to 50 mm)
The typical range of hailstone sizes

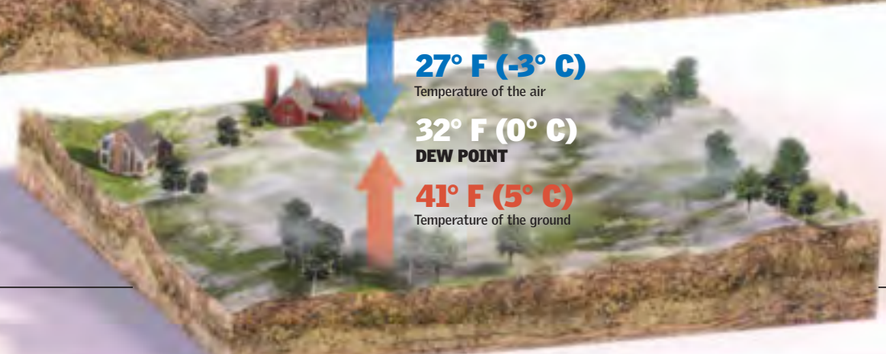
2 pounds (1 kg)
The heaviest hailstones
that fell on April 14, 1986, in Gopalganj, Bangladesh.

HYDROMETEORS

Drops of condensed or frozen water in the atmosphere are called hydrometeors. These include rain, fog, hail, mist, snow, and frost.

DEW

Water vapor that condenses during the night into very small drops. The condensation forms on surfaces that radiate heat during the night, such as plants, animals, and buildings.



27° F (-3° C)
Temperature of the air

32° F (0° C)
DEW POINT

41° F (5° C)
Temperature of the ground

FROST

Frost forms when the dew point of the air is less than 32° F (0° C), and the water vapor transforms directly into ice when it is deposited on surfaces.

HOAR FROST

Similar to frost but thicker. It usually forms when there is fog.

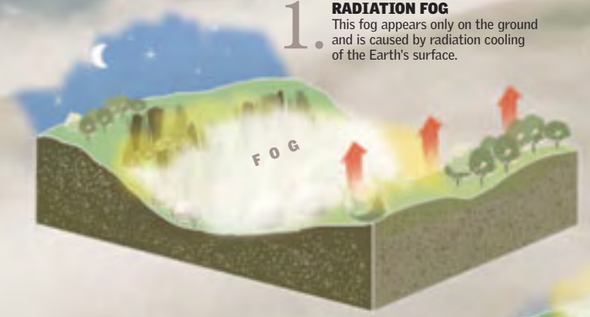
Lost in the Fog

When atmospheric water vapor condenses near the ground, it forms fog and mist. The fog consists of small droplets of water mixed with smoke and dust particles. Physically the fog is a cloud, but the difference between the two lies in their formation. A cloud develops when the air rises and cools, whereas fog forms when the air is in contact with the ground, which cools it and condenses the water vapor. The atmospheric phenomenon of fog decreases visibility to distances of less than 1 mile (1.6 km) and can affect ground, maritime, and air traffic. When the fog is light, it is called mist. In this case, visibility is reduced to 2 miles (3.2 km).

Types of Fog

Radiation fog forms during cold nights when the land loses the heat that was absorbed during the day. Frontal fog forms when water that is falling has a higher temperature than the surrounding air; the drops of rain evaporate, and the air tends to become saturated. These fogs are thick and persistent. Advection fog occurs when humid, warm air flows over a surface so cold that it causes the water vapor from the air to condense.

1. RADIATION FOG
This fog appears only on the ground and is caused by radiation cooling of the Earth's surface.



2. FRONTAL FOG
Formed ahead of a warm front

3. ADVECTION FOG
Formed when a mass of humid and cool air moves over a surface that is colder than the air

Orographic barrier
Fog develops on lee-side mountain slopes at high altitudes and occurs when the air becomes saturated with moisture.

4. OROGRAPHIC FOG

The air becomes saturated as it ascends.

ASCENDING AIR

Dew
The condensation of water vapor on objects that have radiated enough heat to decrease their temperature below the dew point

Mist
Mist consists of salt and other dry particles imperceptible to the naked eye. When the concentration of these particles is very high, the clarity, color, texture, and form of objects we see are diminished.

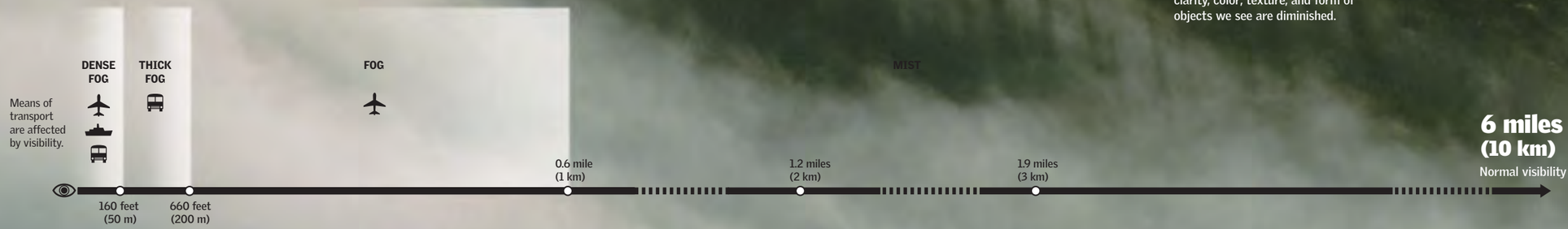
INVERSION FOG
When a current of warm, humid air flows over the cold water of an ocean or lake, an inversion fog can form. The warm air is cooled by the water, and its moisture condenses into droplets. The warm air traps the cooled air below it, near the surface. High coastal landmasses prevent this type of fog from penetrating very far inland.

160 feet (50 m)

The densest fog affects visibility at this distance and has repercussions on car, boat, and airplane traffic. In many cases, visibility can be zero.

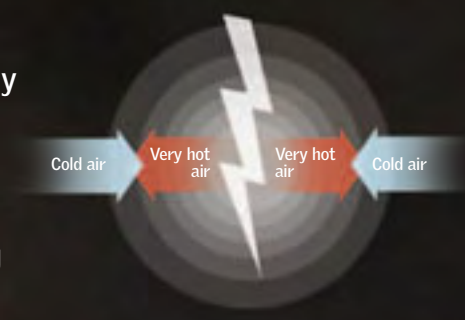
Fog and Visibility

Visibility is defined as a measure of an observer's ability to recognize objects at a distance through the atmosphere. It is expressed in miles and indicates the visual limit imposed by the presence of fog, mist, dust, smoke, or any type of artificial or natural precipitation in the atmosphere. The different degrees of fog density have various effects on maritime, land, and air traffic.



Brief Flash

Electrical storms are produced in large cumulonimbus-type clouds, which typically bring heavy rains in addition to lightning and thunder. The storms form in areas of low pressure, where the air is warm and less dense than the surrounding atmosphere. Inside the cloud, an enormous electrical charge accumulates, which is then discharged with a zigzag flash between the cloud and the ground, between the cloud and the air, or between one cloud and another. This is how the flash of lightning is unleashed. Moreover, the heat that is released during the discharge generates an expansion and contraction of the air that is called thunder.

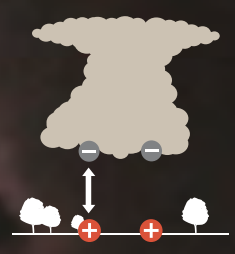


THUNDER
This is the sound produced by the air when it expands very rapidly, generating shock waves as it is heated.

1. ORIGIN
Lightning originates within large cumulonimbus storm clouds. Lightning bolts can have negative or positive electric charges.

2. INSIDE THE CLOUD
Electrical charges are produced from the collisions between ice or hail crystals. Warm air currents rise, causing the charges in the cloud to shift.

SEPARATION
The charges become separated, with the positive charges accumulating at the top of the cloud and the negative charges at the base.



3. ELECTRICAL CHARGES
The cloud's negative charges are attracted to the positive charges of the ground. The difference in electrical potential between the two regions produces the discharge.

INDUCED CHARGE
The negative charge of the base of the cloud induces a positive charge in the ground below it.

4. DISCHARGE
The discharge takes place from the cloud toward the ground after the stepped leader, a channel of ionized air, extends down to the ground.

TYPES OF LIGHTNING

Lightning can be distinguished primarily by the path taken by the electrical charges that cause them.

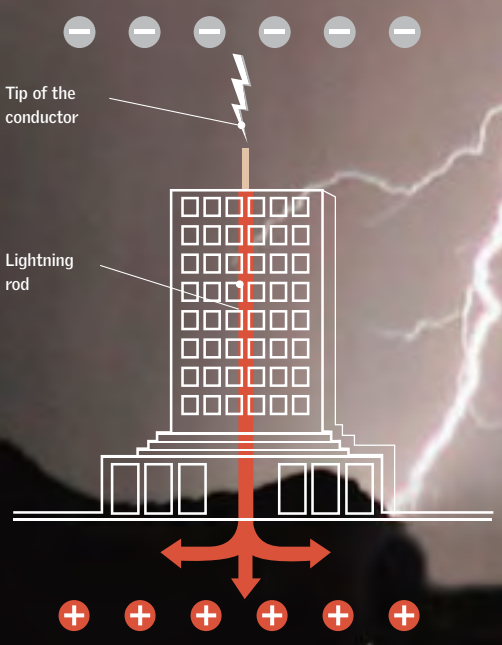
Cloud-to-air
The electricity moves from the cloud toward an air mass of opposite charge.

Cloud-to-cloud
A lightning flash can occur within a cloud or between two oppositely charged areas.

Cloud-to-ground
Negative charges of the cloud are attracted by the positive charges of the ground.

LIGHTNING RODS

The primary function of lightning rods is to facilitate the electrostatic discharge, which follows the path of least electrical resistance.



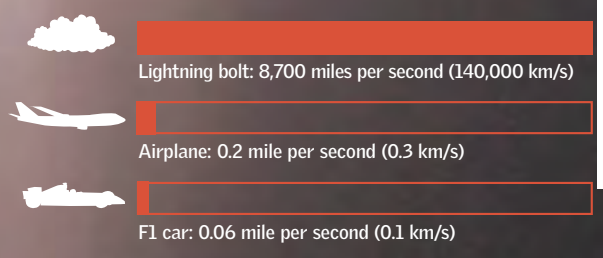
A lightning rod is an instrument whose purpose is to attract a lightning bolt and channel the electrical discharge to the ground so that it does no harm to buildings or people. A famous experiment by Benjamin Franklin led to the invention of this apparatus. During a lightning storm, he flew a kite into clouds, and it received a strong discharge. That marked the birth of the lightning rod, which consists of an iron rod placed on the highest point of the object to be protected and connected to the ground by a metallic, insulated conductor. The principle of all lightning rods, which terminate in one or more points, is to attract and conduct the lightning bolt to the ground.

POINT OF IMPACT

65 feet (20 m)

This is the radius of a lightning bolt's effective range on the surface of the Earth.

8,700 miles per second (140,000 km/s) speed



100 million volts

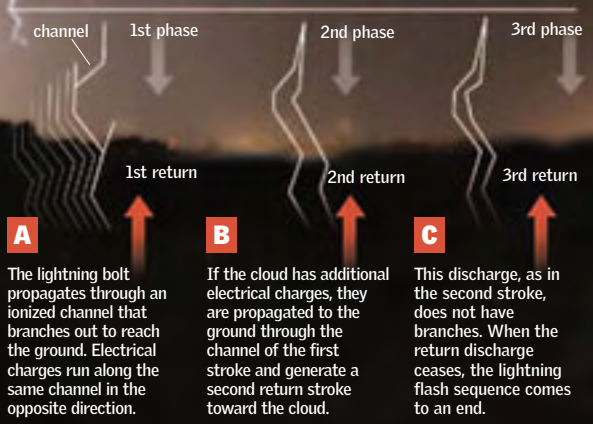
IS THE ELECTRICAL POTENTIAL OF A LIGHTNING BOLT.

A windmill generates 200 volts.

110 volts is consumed by a lamp.

5. RETURN STROKE In the final phase, the discharge rises from the Earth to the cloud.

DISCHARGE SEQUENCE



A The lightning bolt propagates through an ionized channel that branches out to reach the ground. Electrical charges run along the same channel in the opposite direction.

B If the cloud has additional electrical charges, they are propagated to the ground through the channel of the first stroke and generate a second return stroke toward the cloud.

C This discharge, as in the second stroke, does not have branches. When the return discharge ceases, the lightning flash sequence comes to an end.

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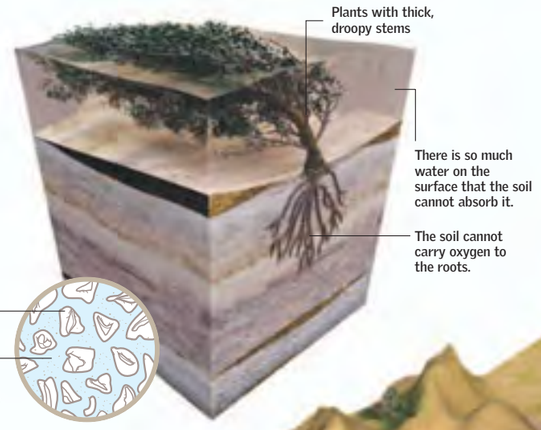
When Water Accumulates

Water is a vital element for life, but in excess it leads to serious consequences for people and their economic activity. Flooding occurs when certain areas that are normally dry are covered with water for a more or less prolonged period. The most important causes are excessive rains, the overflow of rivers and lakes, and giant waves that wash over the coast. Such waves can be the result of unusually high tides caused by strong surface winds or by submarine earthquakes. Walls, dikes, dams, and embankments are used to help prevent flooding.

Flooded Land

When land is flooded for days or months, the air in the soil is replaced by water, which prevents the buildup of oxygen, thus affecting the biological activity of plants and the soil itself. In the latter case, if the water does not have sufficient salt, the incomplete decomposition of organic matter and the significant washing away of nutrients make the soil more acidic. If the water contains a great deal of salt, the salt will remain in the soil, causing a different problem: salinization.



Reduction

The components of the soil that are oxidized can be reduced and thus change their properties.

Floodplains

Floodplains are areas adjacent to rivers or streams that are subject to recurrent flooding.

Torrential Rains

Caused by low pressure systems, instability of the air mass, and high humidity

Torrential rains raise the level of the water in the rivers and the riverbeds.

Snow increases runoff into the rivers.

Little or no rain penetrates into the valley slopes covered with pines.

Principal river

Tributary river

Low-lying terrain
The main river cannot contain the increased flow of the tributary rivers.

Large rivers cross the plains, which suffer from regular flooding

Houses and trees covered with water

Natural course of the river

Hydroelectric dam

Flood Control

With the construction of dikes and embankments, the flow of rivers prone to flooding is largely contained.

Agriculture is more productive when water can be controlled.

Channeling water via turbines also generates electricity.

Electrical energy can be made available to houses.

EMBANKMENT
Earthen embankments help contain rivers that tend to overflow and temporarily change course.

STORM DIKES
In areas where the coast is low and exposed to flooding, protective dikes have been constructed against high tides and powerful waves.

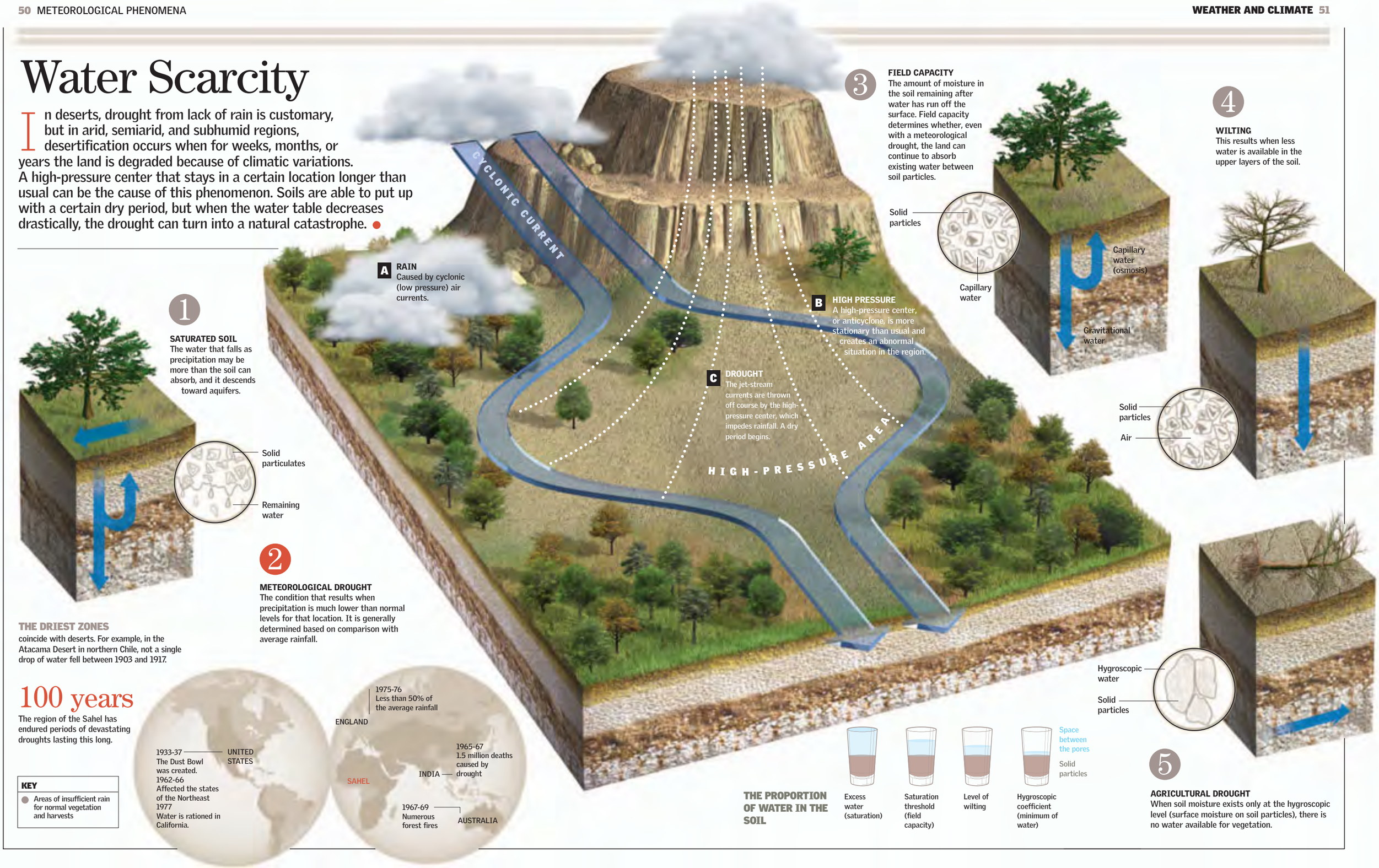
Hydroelectric Plants

use the force and velocity of running water to turn turbines. There are two types: run-off-river (which uses the natural kinetic energy of the river's running waters) and reservoir (where the water accumulates behind dams and is then released under increased pressure to the power plant).

250,000
Victims of flooding in the Bay of Bengal, Bangladesh, in 1970

Water Scarcity

In deserts, drought from lack of rain is customary, but in arid, semiarid, and subhumid regions, desertification occurs when for weeks, months, or years the land is degraded because of climatic variations. A high-pressure center that stays in a certain location longer than usual can be the cause of this phenomenon. Soils are able to put up with a certain dry period, but when the water table decreases drastically, the drought can turn into a natural catastrophe.



THE DRIEST ZONES

coincide with deserts. For example, in the Atacama Desert in northern Chile, not a single drop of water fell between 1903 and 1917.

100 years

The region of the Sahel has endured periods of devastating droughts lasting this long.

KEY

- Areas of insufficient rain for normal vegetation and harvests

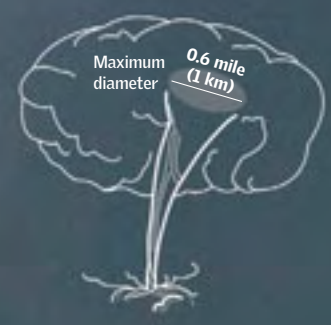
THE PROPORTION OF WATER IN THE SOIL

Lethal Force

Tornadoes are the most violent storms of nature. They are generated by electrical storms (or sometimes as the result of a hurricane), and they take the form of powerful funnel-shaped whirlwinds that extend from the sky to the ground. In these storms, moving air is mixed with soil and other matter rotating at velocities as high as 300 miles per hour (480 km/h). They can uproot trees, destroy buildings, and turn harmless objects into deadly airborne projectiles. A tornado can devastate a whole neighborhood within seconds.

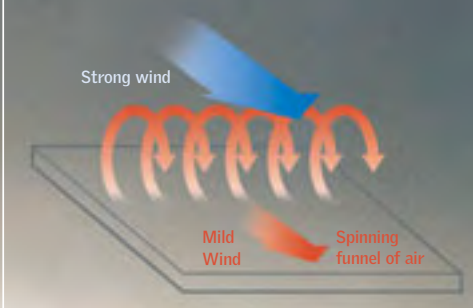
TOP
The top of the tornado remains inside the cloud.

6 miles (10 km)
Maximum height that it can attain



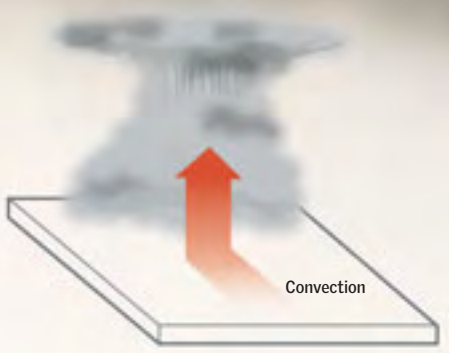
How They Form

Tornadoes begin to form when a current of warm air ascends inside a cumulonimbus cloud and begins to rotate under the influence of winds in the upper part of the cloud. From the base of the column, air is sucked toward the inside of the turning spiral. The air rotates faster as it approaches the center of the column. This increases the force of the ascending current, and the column continues to grow until it stretches from high in the clouds to the ground. Because of their short duration, they are difficult to study and predict.



1.

BEGINNING OF A TORNADO
When the winds meet, they cause the air to rotate in a clockwise direction in the Southern Hemisphere and in the reverse direction in the Northern Hemisphere.



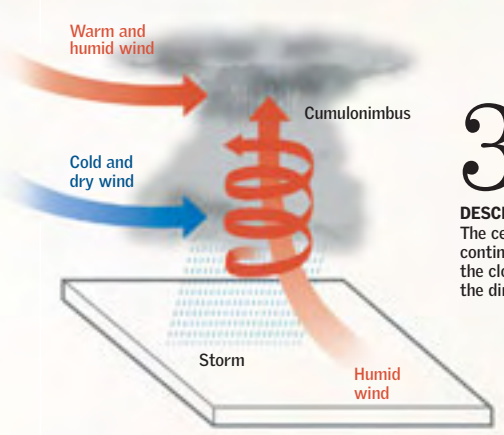
2.

ROTATION
The circulation of the air causes a decrease in pressure at the center of the storm, creating a central column of air.

300 miles per hour (480 km/h)
Maximum velocity the tornado winds can attain

VORTEX
Column of air that forms the lower part of a tornado; a funnel that generates violent winds and draws in air. It usually acquires the dark color of the dust it sucks up from the ground, but it can be invisible.

MULTIPLE VORTICES
Some tornadoes have a number of vortices.



3.

DESCENT
The central whirling column continues to descend within the cloud, perforating it in the direction of the ground.

Where and When

Most tornadoes occur in agricultural areas. The humidity and heat of the spring and summer are required to feed the storms that produce them. In order to grow, crops require both the humidity and temperature variations associated with the seasons.

1,000
tornadoes are generated on average annually in the United States.

3:00 P.M.-9:00 P.M.
The period of the day with the highest probability of tornado formation

4.

THE OUTCOME
The tornado reaches the Earth and depending on its intensity can send the roofs of buildings flying.

SPIRALING WINDS
First a cloud funnel appears that can then extend to touch the ground.

PATH
Normally the tornado path is no more than 160 to 330 feet (50-100 m) wide.

The tornado generally moves from the southwest to the northeast.

Some tornadoes are so powerful that they can rip the roofs off houses.

125 miles (200 km)
The length of the path along the ground over which a tornado can move

FUJITA SCALE

The Fujita-Pearson scale was created by Theodore Fujita to classify tornadoes according to the damage caused by the wind, from the lightest to the most severe.

	F0	F1	F2	F3	F4	F5
WIND VELOCITY MILES PER HOUR (KM/H)	40-72 (64-116)	73-112 (117-180)	113-157 (181-253)	158-206 (254-332)	207-260 (333-418)	261-320 (420-512)
CATEGORY	F0	F1	F2	F3	F4	F5
EFFECTS	Damage to chimneys, tree branches broken	Mobile homes ripped from their foundations	Mobile homes destroyed, trees felled	Roofs and walls demolished, cars and trains overturned	Solidly built walls blown down	Houses uprooted from their foundations and dragged great distances

Death and Destruction

Of the 1,000 tornadoes that annually strike the United States, there is one that has the unfortunate distinction of being one of the worst: the Tri-State tornado, which occurred on March 18, 1925, and caused extreme devastation. It moved across Missouri, Illinois, and Indiana, destroying homes and causing the confirmed deaths of 695 people, although it is believed that the number may have been much higher. The tornado traveled 230 miles (368 km) at an average velocity of 66 miles an hour (105 km/h), and its duration set a record at three hours and 30 minutes. It has been rated on the Fujita scale as an F5 tornado—one of the most damaging—and caused losses to the United States of $17 million.

MISSOURI (U.S.)
Latitude 37° N
Longitude 93° W

Value on the Fujita scale	**F5**
Duration	**3 hours 30 minutes**
Average velocity	**66 miles per hour (105 km/h)**

1:01 P.M.
First contact with the ground

ELLINGTON
First town affected
One dead

REDFORD
Town hit by tornado

ANNAPOLIS AND LEADANNA
Large number of victims
75 injured and 2 dead

90 percent destroyed

BIEHLE
A number of houses destroyed

100 percent destroyed

30 percent destroyed

DE SOTO
Partial destruction but a large number of victims
69 dead

GORHAM
Town in ruins
34 dead

MURPHYSBORO
Town with the greatest number of fatalities
234 dead

40 percent destroyed

71 miles per hour (115 km/h)
66 miles per hour (107 km/h)
60 miles per hour (96 km/h)

MISSOURI

230 miles (368 km) TOTAL PATH TRAVELLED
190 miles (307.5 km)
38 miles (60.5 km)
9° of rotation
65 miles per hour (104 km/h) Average velocity
70 miles per hour (115 km/h) Velocity

90 percent destroyed

PARRISH
Almost total destruction
22 dead

Rural area

55 miles per hour (90 km/h)
60 miles per hour (96 km/h)
71 miles per hour (115 km/h)

In **40 minutes, 541 people died.**

WEST FRANKFORT
Partial destruction
450 wounded and 127 dead

20 percent destroyed

100 percent destroyed

GRIFFIN
150 houses destroyed, and many children killed.

OWENSVILLE
Serious damage to houses

4:30 P.M.
Final contact with the ground

INDIANA

PRINCETON
Half of the town destroyed
65 deaths

50 percent destroyed

ILLINOIS

THE TOWN OF GRIFFIN, IN THE STATE OF INDIANA, WAS LEFT IN RUINS.

15,000
houses destroyed

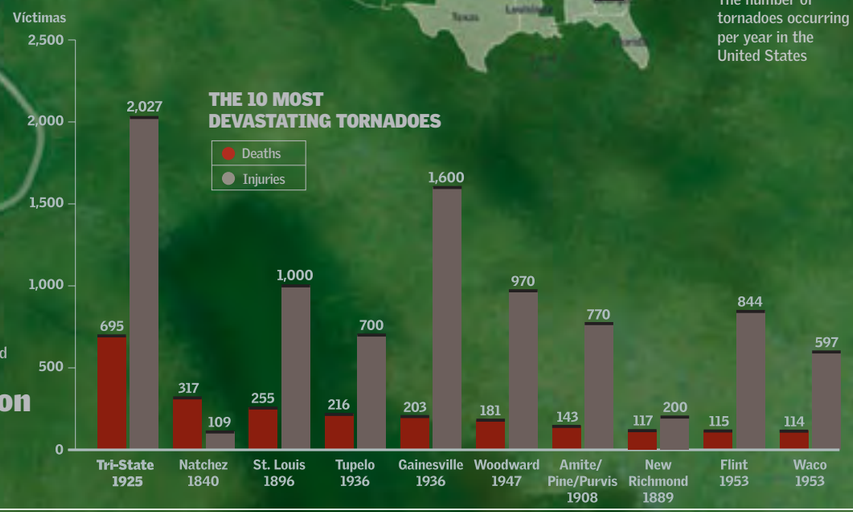
17 million
dollars in losses

Tornadoes in the United States

Unlike hurricanes, which are tropical storms primarily affecting the Gulf of Mexico, tornadoes are phenomena that occur between the Great Plains of the United States, the Rocky Mountains, and the Gulf of Mexico and usually appear in the spring and summer.

3:00 P.M. -9:00 P.M.
The period of the day with the highest probability of tornado formation

1,000
The number of tornadoes occurring per year in the United States



Anatomy of a Hurricane

A hurricane, with its ferocious winds, banks of clouds, and torrential rains, is the most spectacular meteorological phenomenon of the Earth's weather. It is characterized by an intense low-pressure center surrounded by cloud bands arranged in spiral form; these rotate around the eye of the hurricane in a clockwise direction in the Southern Hemisphere and in the opposite direction in the Northern Hemisphere. While tornadoes are brief and relatively limited, hurricanes are enormous and slow-moving, and their passage usually takes many lives.

NH
Hurricanes in the Northern Hemisphere rotate counterclockwise, and those in the Southern Hemisphere rotate clockwise.

SH

DAY 1
A jumble of clouds is formed.

DAY 2
The clouds begin to rotate.

DAY 3
The spiral form becomes more defined.

DAY 6
Now mature, it displays a visible eye.

DANGER ZONE

The areas that are vulnerable to hurricanes in the United States include the Atlantic coast and the coast along the Gulf of Mexico, from Texas to Maine. The Caribbean and the tropical areas of the western Pacific, including Hawaii, Guam, American Samoa, and Saipan, are also zones frequented by hurricanes.

DAY 12
The hurricane begins to break apart when it makes landfall.

1. BIRTH

Forms over warm seas, aided by winds in opposing directions, high temperatures, humidity, and the rotation of the Earth

2. DEVELOPMENT

Begins to ascend, twisting in a spiral around a low-pressure zone

3. DEATH

As they pass from the sea to the land, they cause enormous damage. Hurricanes gradually dissipate over land from the lack of water vapor.

FRINGES OF STORM CLOUDS
otate violently around the central zone.

THE EYE
Central area, has very low pressure

Descending air currents

The high-altitude winds blow from outside the storm.

The air wraps around the eye.

Cloud bands in the form of a spiral

EYE WALL
The strongest winds are formed.

VAPOR
Rises warm from the sea, forming a column of clouds. It rises 3,900 feet (1,200 m) in the center of the storm.

Strong ascendant currents

80° F
(27° C)
is the minimum temperature that water on the surface of the ocean will evaporate at.

The trade winds are pulled toward the storm.

WIND ACTIVITY

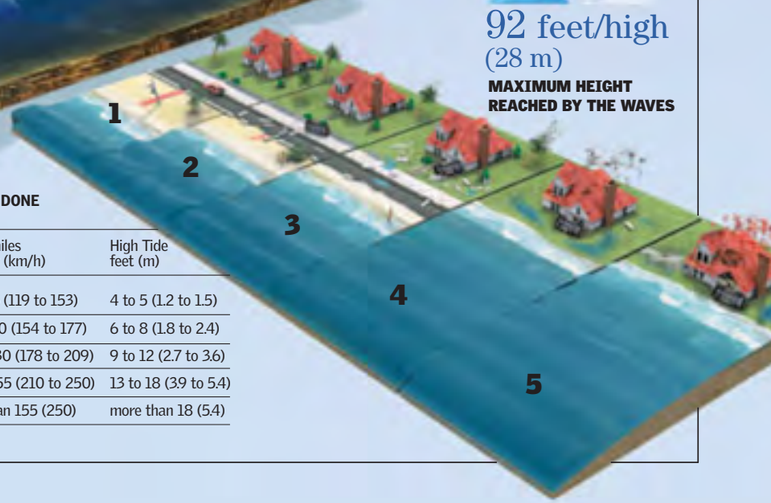
Light winds give it direction and permit it to grow.

The winds flow outward.

19 miles per hour
(30 km/h)
VELOCITY AT WHICH IT APPROACHES THE COAST

FRICTION
When the hurricane reaches the mainland, it moves more slowly; it is very destructive in this stage, since it is here that populated cities are located.

PATH OF THE HURRICANE



92 feet/high
(28 m)
MAXIMUM HEIGHT REACHED BY THE WAVES

CLASSIFICATION OF DAMAGE DONE
Saffir-Simpson category

	Damage	Speed miles per hour (km/h)	High Tide feet (m)
CLASS 1	minimum	74 to 95 (119 to 153)	4 to 5 (1.2 to 1.5)
CLASS 2	moderate	96 to 110 (154 to 177)	6 to 8 (1.8 to 2.4)
CLASS 3	extensive	111 to 130 (178 to 209)	9 to 12 (2.7 to 3.6)
CLASS 4	extreme	131 to 155 (210 to 250)	13 to 18 (3.9 to 5.4)
CLASS 5	catastrophic	more than 155 (250)	more than 18 (5.4)

What Katrina Took Away

Hurricane Katrina lashed the south and the center of the United States in August 2005. The force of the wind razed thousands of houses, buildings, oil installations, highways, and bridges, leaving a vast area of the country without communication and some heavily populated areas without provisions. It resulted in extensive material damage and thousands of deaths in Florida, the Bahamas, Louisiana, and Mississippi. Satellite images reveal the scope of the disaster, considered one of the most devastating in the history of the country.

THE WATER
advances toward the city, invading the central regions.

THE WINDS
At 155 miles per hour (250 km/h), they force the water against the protective walls..

LAKE PONTCHARTRAIN

DIKES
were breached by the water and the wind, causing a great flood.

6:00 A.M.
The time when the hurricane made landfall

17TH STREET CANAL

LONDON AVENUE CANAL

ORLEANS AVENUE CANAL

80%
Area of New Orleans affected by flooding

Area most affected by the flood

Areas most affected by the flood

75%
of the inhabitants of this zone were evacuated.

OVER 1,500
Deaths confirmed after Katrina

OVER 75 billion
dollars was the cost of the repairs.

The hurricane winds pushed the water 14 feet (4.3 m) above the normal sea level.

Along with the storm, the backed-up water reaches the dikes of the Mississippi River.

NEW ORLEANS
Latitude 30° N
Longitude 90° W

Area	360 square miles (933 square kilometers)
Number of inhabitants	500,000
Altitude (above sea level)	10 feet (3 m)

AUGUST 23
A tropical depression forms in the Bahamas. It intensifies and becomes tropical storm Katrina. On August 25, it makes landfall in Florida as a category 1 hurricane.

14 Huracanes fueron registrados en 2005.

26 El total de tormentas tropicales registradas en el año 2005.

AUGUST 27
Leaves the Gulf of Mexico and reaches category 3. On August 28, it is transformed from category 3 to category 5 and increases in size.

CATEGORY 5

CATEGORY 3

AUGUST 29
In the early hours, it makes landfall in Louisiana as a category 4 hurricane. A little later, it makes landfall for the third time, in Mississippi.

CATEGORY 4

155 miles per hour (250 km/h)
MAXIMUM WIND SPEED

SEPTEMBER 1
What remains of the hurricane is weakened as it moves north to Canada, where it dissipates.

Direction of the hurricane

Foresight to Prevent Tragedies

Hurricanes usually lash specific regions of the planet, and the population must become aware of the disasters that can strike the community. Each family must know which area of the house is the most secure in case the roof, a door, or a window collapses. They must also know when it is time to go to a shelter or if it is better to remain at home. Another important precaution is to organize and store all family documents and real-estate records in a water- and fireproof strongbox.

1 BEFORE THE HURRICANE

If you live in a hurricane-prone area, it is recommended that you know the emergency plans of the community and that you have a plan of action for your family.

2 DURING THE HURRICANE

The important thing is to remain calm and to stay informed via radio or television about the path of the hurricane. Move away from doors and windows. Do not leave until the authorities announce the danger from the hurricane has ended.

3 AFTER THE HURRICANE

First verify that everyone in the family is well and that there are no injuries. Do not touch loose cables or fallen poles. Call the fire department or the police in case you need food, clothing, or immediate medication.

Secure all the doors and windows to keep them from opening.

Reinforce roof tiles to keep them from being loosened.

Store nonperishable food and potable water.

Keep valuable objects and documents in a waterproof container.

Follow news reports with a battery-powered radio.

Keep the car supplied with a full tank of fuel just in case.

Administer first aid when necessary.

Disconnect all electrical devices and shut off the house circuit breaker.

Use a battery-powered radio to tune into local stations to get information.

Help people who are injured or trapped.

Keep documents confirming your ownership of property close at hand.

Return home only when the authorities say that it is safe.

Do not drink water unless you are sure it is potable.

Use the telephone only for emergency calls.

Verify that there are no natural-gas leaks or damage to the electrical system.

Check the most fire-prone areas.

Do not touch wires or damaged electrical equipment.

Turn off the main water valve and the main gas valve.

When you are on the move, use caution whether on foot or driving.

HOW TO PREPARE EMERGENCY EQUIPMENT

A complete first-aid kit must be prepared and available. Consult a pharmacist or your family physician.

First-aid kit
Check the first-aid kit and replace any expired items.

First-aid course
You should be prepared for dealing with the most common symptoms and injuries.

HOW TO PREPARE DOCUMENTATION

To be prepared for evacuation, keep family documents in good order.

Inventory
Make a complete list of belongings of each person.

Personal ID
It is important for everyone to have an ID card.

Meteorology

RITA, SEPTEMBER 2003
The image from the GOES-12 satellite shows the configuration of Hurricane Rita in the eastern portion of the Gulf of Mexico.

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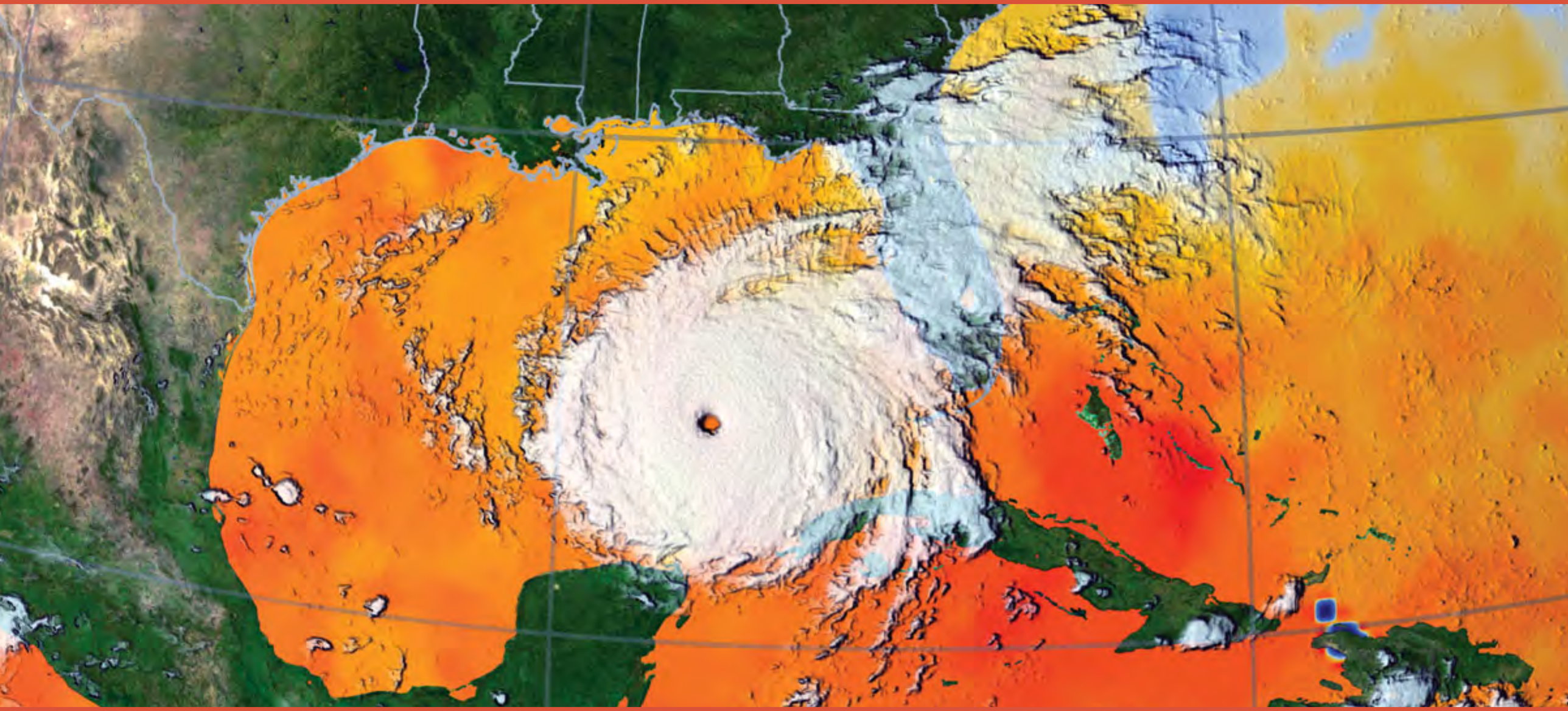


The use of satellites orbiting the Earth, recording the coming of rain, air currents, and clouds, allows us to know with some hours of advance warning if a severe storm is heading toward a certain point on the planet. Counting on this type of precise information about when and where tropical cyclones will occur, for example, has allowed government officials to coordinate the evacuation of people from the affected zones. The surface of the planet is also monitored by a system of meteorological stations placed hundreds of miles from each other. These collect information from and send information to all areas of the world so that meteorologists can prepare maps, graphics, and predictions to inform the public. ●

Weather Folklore

Before the development of meteorology as we know it today, people observed in nature signs that allowed them to predict rains, floods, or strong winds. All this knowledge has been transmitted over the centuries in the form of proverbs or rhymes. Most of these fragments of meteorological knowledge lack a scientific foundation, but some of them reflect certain principles. Plants and animals play a major role in these observations.

Signs from Plants and Animals

In every rural community, concern for the harvest and dependency on weather resulted in a series of beliefs, with varying degrees of accuracy, taken as prophesies of later events. In any case, even though it is certain that people as well as plants and animals react to the current weather, there is nothing to indicate that this might reveal anything about the weather in the future except to the degree that an incipient change is related to the current weather. For example, some signs accompany the increase in humidity that occurs prior to the passage of a cold front.

Swallow

When swallows fly low, get your rain gear in tow.
Swallows usually appear before a heavy rain.

OPEN AND CLOSED PINECONES
Open pinecones mean dry weather; closed pinecones mean humid weather.

DRY SEAWEED
The lower the humidity, the more probable it is that the next day will be dry.

Donkey

I hear donkeys braying; I am sure it will rain today.
The animals react to the existing weather. It is a sign associated with the increase in humidity in the environment.

Toad

When you see a toad walking, it will be a wet spring.
When a toad is swimming in the water, this means it will soon rain. If it stays in the water without moving, the rain will last for some time.

OAK
If the leaves of the oak fall before those of the ash, the summer will be dry.

ASH
If the leaves of the ash fall before those of the oak, the summer will be wet.

Moon

When the Moon has a halo, tomorrow will have wet or bad weather.
Halos occur as a consequence of the refraction of light by ice crystals in cirrostratus clouds covering the Sun or Moon. They portend a warm front, which will be followed by rain.

Almanac Forecasts

In the 16th century, almanacs with weather forecasts were sold throughout Europe. Each month of the year has its own refrain, although this depends on the hemisphere a person lives in. The monthly and annual calendars offered agricultural and medical advice. From the most remote times, there was a general belief that the Moon determined the behavior of the atmosphere and that variations in the weather were caused by changes in the phase of the Moon. Some examples of these popular sayings are: "Sweet April showers do spring May flowers;" "After a dark winter's night, the next day will be bright."

Clouds

Clouds with a fringe or lining—secure your sails well.
This relates to clouds that are carried by winds at high altitudes; these clouds are often a sign that a low-pressure system, or cyclone, is approaching.

WEATHER PREDICTION
There are thousands of refrains that refer to changes in weather conditions. Here are some examples.

WIND
Wind from the east, rain like a beast.

MORNING DEW
Dew and cool in May, bring wine to the vine and hay to the cow.

CLEAR SUNSET
Rainbow at sundown, good weather at dawn.

Snails

When you see a black slug in your way, rain is not far away.
Snails are usually hidden in the garden. You see them only on humid days, just prior to the rain.

Compilation of Information

Most of the information available regarding climatic data comes from the record that meteorologists everywhere in the world keep regarding cloud cover, temperature, the force and direction of the wind, air pressure, visibility, and precipitation. Then from each meteorological station, the data is sent by radio or satellite, and this makes it possible to make forecasts and maps.

ANEROID BAROMETER
measures atmospheric pressure. Changes are shown by the pointers.

Scale
Spring
Spiral spring
Metal drum
Levers
Chains

Atmospheric pressure
Vacuum
760 mm
Mercury

MERCURY BAROMETER
An instrument used to measure atmospheric pressure. It consists of a glass tube full of mercury, with the open end submerged in a reservoir.

Radar

BAROGRAPH
measures the atmospheric pressure and records its changes over time.

WEATHER VANE
shows which way the wind is blowing. It is a perfectly balanced mechanical system.

Indicates the direction of the wind
Three equally spaced cups record the intensity of the wind.
DATA RECORDER
records the data obtained.

ANEMOMETER
measures the speed of the wind. This instrument is activated by the wind, which turns three hemispherical cups mounted on a vertical rod firmly placed in the ground.

MAXIMUM THERMOMETER
shows the highest temperature of the day. The capillary with mercury is calibrated in the bulb.

Bulb with mercury
Bulb with alcohol
2 °

MINIMUM THERMOMETER
indicates the lowest temperature of the day. It has a fork-shaped bulb.

HYGROTHERMOGRAPH
simultaneously records the air temperature and relative humidity. A thermograph and a hygrograph independently make records on paper of the daily variations in temperature and humidity.

PSYCHROMETER
measures the relative humidity of the air. It consists of two thermometers and two bulbs (one dry and one covered with muslin that is always kept damp).

Dry-bulb thermometer
Wet-bulb thermometer
Container of distilled water

Workplace

A typical meteorological station checks the temperature, humidity, wind velocity and direction, solar radiation, rain, and barometric pressure. In some places, soil temperature and flow of nearby rivers are also monitored. The compilation of this data makes it possible to predict different meteorological phenomena.

METEOROLOGICAL SHELTER
It is built of wood or fiberglass on a base that insulates it from the soil and protects certain instruments (thermometers, psychrometers, and others) from solar radiation. Screens in the windows ensure good ventilation.

Double circulation of the air to prevent the heating of the instruments when the radiation is very intense
Psychrometer
Maximum and minimum thermometers
Hygrothermograph
Slats allow the air to flow through freely without creating currents.

Weather vane
Anemometer
Data recorder
Solar panel
Control unit
Rain Meter

Weather Station

Meteorologists collect data at different heights. They use various instruments at ground level: a thermometer for temperature, a hygrometer for humidity, and a barometer for atmospheric pressure.

In the Northern Hemisphere, the doors should be oriented toward the north to prevent the Sun's rays from striking the instruments when observations are being made.

Thermometer
Mouth
Drum
Recording pen
Siphon
Collector container
Wooden platform

EVAPORIMETER
As its name indicates, it measures the effective evaporation of water from a mass of liquid in the open air, from its loss from the surface through transformation to water vapor.

RAIN METER
This is used to keep a chronological record of the amount of water falling as rain.

RAIN GAUGE
The precipitation that falls on the ground in the form of rain is collected by the rain gauge.

The light strikes and is concentrated as it traverses the sphere.

HELIOPHANOGRAPH
An instrument used to measure the number of hours of sunlight. It consists of a glass sphere that acts as a lens to concentrate sunlight. The light is projected onto a piece of cardboard behind the sphere. The cardboard is burned according to the intensity of the light.

IMPRESSION
The concentrated rays of sunlight burn cardboard placed behind the glass sphere.

Record on a strip of cardboard graduated in hours
The intervals burned give a count of the hours of sunlight during the day.

Automatic Weather Station

An automatic meteorological station uses electrical sensors to record temperature, humidity, wind velocity and direction, atmospheric pressure, and rainfall, among other parameters. The readings are processed by microprocessors and transmitted via an automatic system. This station functions autonomously, 24 hours a day, powered by solar energy (solar panels) or wind energy.

Instantaneous Maps

Weather maps represent at any given moment the state of the atmosphere at different altitudes. These maps are made based on the information provided by meteorological stations and are useful for specialists. The data collected by them include various values for pressure and temperature that make it possible to forecast the probability of precipitation, whether the weather will remain stable, or if it will change because a weather front is moving in.

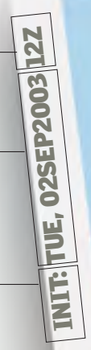
NOMENCLATURE

Every meteorological map carries a label that indicates the date and time it was made.

12 indicates the hour and Z Greenwich Mean Time.

This map is prepared with the initial values of Tuesday, September 2.

It indicates the initial values.



1686
is the year in which English astronomer Edmond Halley made the first meteorological map.

SYMBOLS

There are a number of different symbols to represent different kinds of fronts.

WARM A warm air mass with local storms is advancing.

COLD A cold air mass with rain is advancing.

STATIONARY Moderately bad weather and little change of temperature

OCCLUDED FRONT
It is mixed; it will act first as a warm front and then as a cold front.

Isobar Maps

One of the variables that provides the most information in real time for knowing meteorological conditions is atmospheric pressure, whose values over land (at sea level) are represented on what are called isobar maps, or ground-level weather maps. The isobars, or lines that connect points of equal pressure, make it possible to estimate the velocity and direction of the wind at ground level. This information helps forecast the movement of cold or warm air masses. The letter A indicates an anticyclonic area, which indicates atmospheric stability and that the probability of rain is very low. The letter B indicates a low-pressure area and presages major atmospheric instability with possible rain.

LOW PRESSURE, OR DEPRESSION

In this zone, atmospheric stability will be low given that the air is rising, and there is a high probability of precipitation.

LOW PRESSURE
This is a low-pressure zone. The pressure increases from the internal isobars toward the external isobars.

1000
995
990

WINDS
circulate around the center of the area.

ANTICYCLONE

In this area, the atmospheric stability is high, since the downward motion of the air prevents the formation of clouds. There is low probability of rain.

WINDS
They circulate and move away from the area.

HIGH PRESSURE
This is a high-pressure area. The pressure decreases from the internal isobars toward the external isobars.

1030
1025
1020
1015

ISOBARS
are lines joining points of equal pressure.

OCCLUDED FRONT
indicates the line of collision between a cold front and a warm front. These are usually associated with severe storms.

Upper-air Map

Another type of map, which is used to analyze upper-air weather conditions, is an upper-level, or geopotential, map. On these maps, contour lines connect points located at the same altitude for a certain pressure level (normally 500 hectopascals [hPa]) and correlate with the temperature of the air in the higher layers of the troposphere (at 16,400 feet [5,000 meters] altitude on the 500 hPa map). The temperature is represented in each region of the troposphere by lines called isotherms.

BAD WEATHER
Instability and high probability of abundant rain

LOW-PRESSURE TROUGH

This phenomenon increases the probability of bad weather. A low-pressure trough has a low geopotential value.

HIGH-PRESSURE RIDGE

Area of high geopotential values in which the chances of rain are slight

GOOD WEATHER
Atmospheric stability and low expectation of precipitation

LOW-PRESSURE TROUGH AXIS

HIGH-PRESSURE RIDGE AXIS

WINDS

The direction and intensity of the winds are indicated by a segment with a circle at its end, which indicates the direction from which the wind is blowing. On this segment, perpendicular lines are traced that indicate the velocity of the wind in knots, where one knot equals 1.2 miles per hour (1.9 km/h).

SYMBOLS
The direction of the wind is represented by these symbols:

POSITION
The line indicates the direction of the wind. It can be north, northeast, east, southeast, south, southwest, west, or northwest.

OVERCAST SKY
A black circle indicates an overcast sky and a white circle a clear sky.

WIND VELOCITY
A short line indicates five knots, a longer line indicates 10 knots, and a terminal triangle indicates more than 40 knots.

UPPER-LEVEL MAPS

The contour lines traced in these charts connect points of equal geopotential height, which define high-pressure ridges and low-pressure troughs. The wind direction is parallel to these lines. These charts are used to prepare weather forecasts.

250 hPa	36,100 FEET (11,000 METERS)
500 hPa	18,000 FEET (5,500 METERS)
700 hPa	9,800 FEET (3,000 METERS)
850 hPa	4,900 FEET (1,500 METERS)
SURFACE	0 FEET (0 METERS)

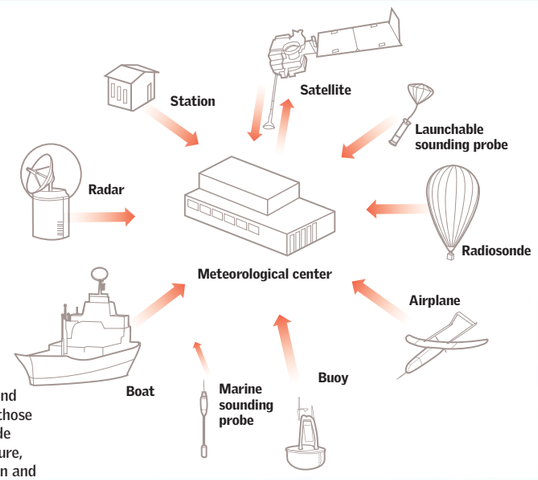
500 HPA
The first pressure value that represents a geopotential of 500 hectopascals (hPa)

600 596 592 588 584 580 576 572 568 564 560 556 552 548 544 540 536 532 528 524 520 516 512 508 504 500 496 492 488 484 480 476

Rain, Cold, or Heat

Knowing ahead of time what the weather will be is sometimes a question of life or death. The damage resulting from a torrential rain or a heavy snowfall can be avoided thanks to the forecasts of meteorologists. The forecasts they make are based on information gathered from many sources, including instruments on the ground, in the air, and at sea. Despite the use of sophisticated information systems, the weather can be forecast only for the next few hours or days. Nonetheless, it is very useful in helping to prevent major catastrophes.

DATA COLLECTION
The World Meteorological Organization acts as a center for receiving and transmitting data coming from various stations located in the air, on the ocean, and on land.



On Land

The observations made at ground level are more numerous than those made at higher altitudes. They include measurements of atmospheric pressure, temperature, humidity, wind direction and velocity, the extent and altitude of cloud cover, visibility, and precipitation.

In the Air

Data can be collected by airplanes, satellites, or sounding probes. One single satellite can cover the entire surface of the Earth. Precise information helps prevent meteorological catastrophes such as hurricanes or flooding.

RADIOSONDE
carries out airborne measurements of temperature, pressure, and relative humidity at different altitudes or atmospheric levels. It also indicates the direction and speed of the wind.

METEOROLOGICAL AIRCRAFT
obtain temperature and humidity data and photograph particles contained in the clouds.

HURRICANE HUNTER P-3 AIRPLANE
Its Doppler radar has a resolution four times greater than the standard Doppler radar in conventional use.

14,000 feet (4,270 m)
is the altitude that can be reached by the P-3 aircraft.

49,200 feet (15,000 m)
is the altitude that a radiosonde can reach.

32,800 feet (10,000 m)
The height at which they fly, near the upper limit of the troposphere

JET G-IV

Doppler radar

Parachutes lengthen the time in the air.

Radiosonde sends information to the base.

1,200 feet (365 m)
is the altitude that can be reached by a radio sounding probe.

AEROSONDE
Pilotless weather aircraft capable of sending meteorological information at intervals of tenths of a second

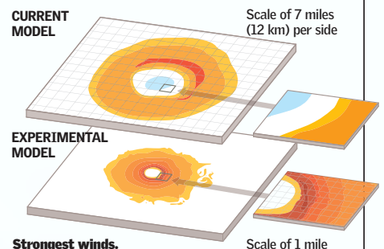
ARTIFICIAL SATELLITES
provide images used for visualizing clouds and water vapor in the atmosphere and for measuring the temperature of land and ocean surfaces.

49,200 feet (13,000 m)
is the altitude that can be reached by the G-IV airplane.

LAUNCHABLE SOUNDING PROBE
is launched from an airplane toward the ground. Its trajectory is followed as it relays information about wind velocity, temperature, humidity, and pressure.

Better Forecasts

New models that measure changes in such variables as humidity, temperature, wind velocity, and cloud displacement may make it possible to improve forecasts by 25 percent over current ones.



METEOROLOGICAL STATION
Measurements at ground level permit the collection of partial data. Thermometers measure temperature, the hygrometer measures humidity, and the barometer measures atmospheric pressure.

OCEANOGRAPHIC SHIP
gathers data on the direction and speed of the wind and the temperature of the air and water, among other things.

METEOROLOGICAL CENTERS
They improve worldwide cooperation in meteorological observations, normalize the data obtained in different cities throughout the world, and promote the application of forecasts to various human activities.

Navigation lights
Anemometer
Data transmitter
Solar panel

METEOROLOGICAL BUOY
provides information about conditions of the sea in areas that are not covered by ships. The buoy floats freely with the ocean currents and transmits readings automatically via satellite.

ACOUSTIC SIGNAL
An acoustic depth sounder sends out sound waves to measure the depth of the water.

6,600 feet (2,000 m)
is the depth reached by the vehicle.

AUTONOMOUS UNDERWATER VEHICLE
Images related to the physical properties of the ocean water, such as the temperature, salinity, and density, are relayed to operators and its location and depth tracked via the Global Positioning System (GPS).

MARITIME SOUNDING PROBES
They are dropped from airplanes and then sink.

RADAR STATION
is utilized to measure the intensity with which rain, snow, or ice is falling. The radar sends radio waves that bounce off raindrops, and the return signal is displayed on a receiving screen.

On the Sea

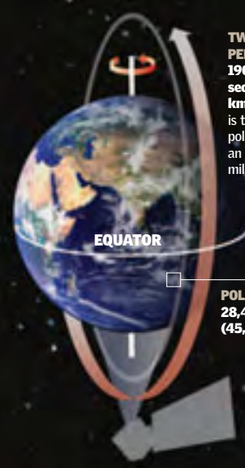
Boats, buoys, and autonomous underwater vehicles help measure water temperature, salinity, density, and reflected sunlight. All the information gathered is sent to a meteorological center.

Mobile Satellites

Meteorological satellites, which have been orbiting the Earth for more than 30 years, are an indispensable aid to scientists. Along with the images generated by these instruments, meteorologists receive data that can be used to prepare weather bulletins. These reports, circulated via the mass media, allow people all over the world to know the weather forecast. Moreover, the most advanced satellites are used to study the characteristics of phenomena such as tropical cyclones (hurricanes, cyclones, and typhoons).

Polar Orbit

They orbit from pole to pole with a synchronized period. As they move in their orbits, they scan swaths of the Earth's surface. They pass over any given point twice a day. Their operational lifetime is approximately two years.



TWO ORBITS PER DAY
190 miles per second (305 km/sec)
is the velocity of a polar satellite at an altitude of 560 miles (900 km).

Geostationary

They orbit the Earth above the Equator and are synchronized with the Earth's rotation—that is, as they orbit the Earth, they are always over the same geographic point on the Earth's surface.

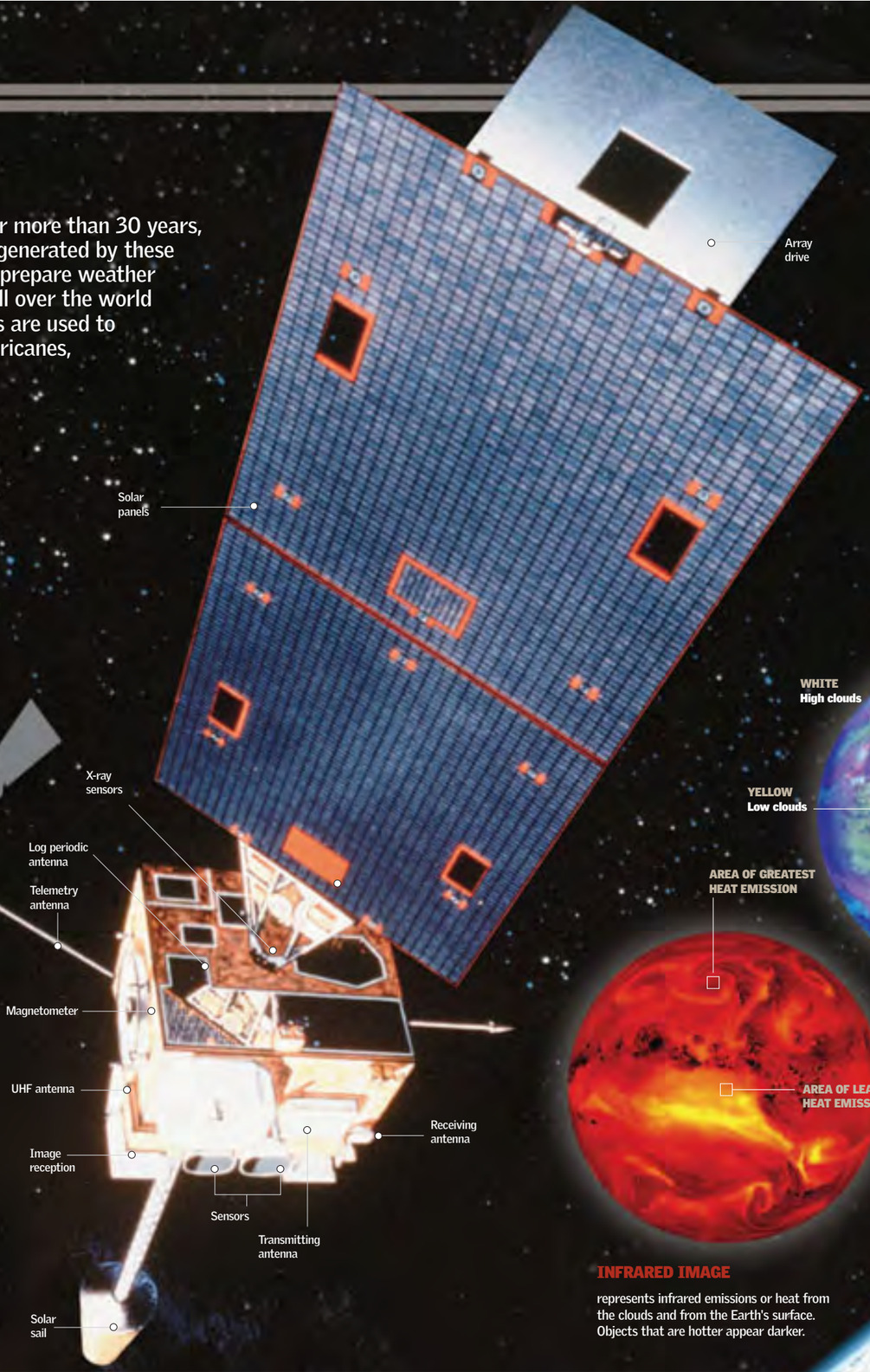
ACCOMPANYING THE EARTH
1,100 miles per second (1,770 km/sec)
The velocity necessary to remain fixed over one point on the Earth

CHARACTERISTICS

ORBITAL ALTITUDE	22,300 miles (35,900 km)
ROTATIONAL VELOCITY	100 RPM
ORBITAL PERIOD	24 hours

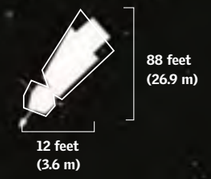
ACTIVE POLAR SATELLITES

ACTIVE GEOSTATIONARY SATELLITES



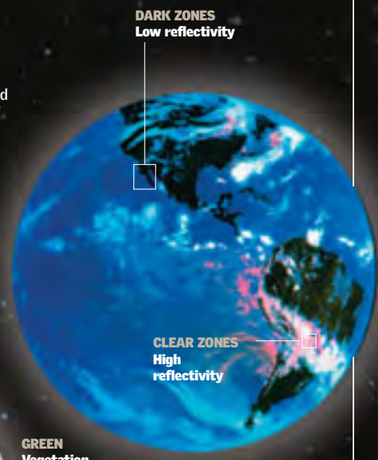
GOES EAST

Orbital altitude	22,370 miles (36,000 km)
Weight	4,850 pounds (2,200 kg)
Launch date	2001
Orbit	75°



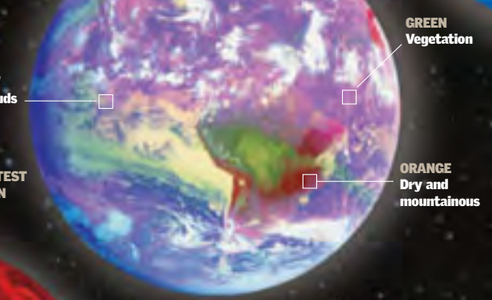
Images, Yesterday and Today

The TIROS satellites (Television and Infra-Red Observation Satellite) of the 1960s provided the first images of cloud systems. The modern GOES satellites (Geostationary Operational Environmental Satellites), which take more precise time and space measurements, provide higher-quality images of clouds, continents, and oceans. They also measure the humidity of the atmosphere and the temperature at ground level.



VISIBLE IMAGE

Oceans and continents have low albedo and appear as darker areas. Areas with high albedo, in contrast, are clear and bright.



COMBINED IMAGES

They are composed of infrared images (which permit differentiation of high and low clouds) and visible-light images (which measure the reflectivity of each climatic subsystem).

INFRARED IMAGE

represents infrared emissions or heat from the clouds and from the Earth's surface. Objects that are hotter appear darker.

Climate Change

GLACIERS IN ALASKA
Approximately 5 percent of the land is covered by glaciers, which advance and break up when they reach the ocean, where they form impressive cliffs of ice.

GODS AND RITUALS 76-77
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CHANGE; EVERYTHING CHANGES 90-91

Mountain glaciers are melting, and this is a threat to the availability of freshwater. It is calculated that 8 cubic miles (35 cu km) of water melts from the glaciers each year, which is the glaciers' major contribution to raising the global sea level; it is thought that the continental ice sheet may play a significantly larger role. The volume of the glaciers in the European Alps and in the Caucasus Mountains has been reduced by half, and in Africa, only 8 percent of the largest glacier of Mount Kenya still exists. If these tendencies continue, by the end of the century, most glaciers will have disappeared completely, including those in Glacier National Park in the United States. That will have powerful repercussions on the water resources of many parts of the world. ●

Gods and Rituals

Predicting the weather was a subject of interest to all the early civilizations that populated the Earth. Greeks, Romans, Egyptians, pre-Columbians, and Orientals venerated the gods of the Sun, the Moon, the heavens, the rain, storms, and the wind for centuries. In their own way, with rituals and praise, they tried to influence the weather to improve the bounty of the harvest.

ZEPHYRUS
The Greek god of the west wind had an important presence. At times he was beneficial, and at other times catastrophic. Though the ancient Greeks were not sure whether the winds were male or female, they did believe the winds had wings.

The Romans

The Romans worshiped many gods because they inherited them from the Greek oracles. The gods of weather were Jupiter (wise and just, who reigned over the earth), Apollo (the god of the sun), Neptune (the god of the sea and storms), and Saturn (the god of agriculture). Each god had a specific function. As a result, any human activity could suffer or benefit from the attitude of the god in charge of that particular function. Thus, the purpose of ritual worship and sacrifice to the gods was to gain their favor.

THE SCEPTER
A symbol of command consisting of ornamented short sticks, the symbol of authority

THE LIGHTNING BOLT
Jupiter reigned over the earth and heaven, and he had the attributes of an eagle, a lightning bolt, and a scepter.

THE EAGLE
Jupiter is the Roman supreme god, represented by the figure of the eagle. He is also first in wisdom and power.

Greeks

The powerful Zeus was the king of the Greek gods and dispenser of divine justice. He was the sovereign of heaven (his brothers Poseidon and Hades governed the ocean and the underworld, respectively). He carried a thunderbolt to represent his power, associated with the weather. Zeus lived on Mount Olympus, from where he could observe and often intervene in the affairs of humans. The Greeks believed that Poseidon, when annoyed, would break up the mountains and throw them into the sea to form islands. Uranus was a personification of heaven for the Greeks, and Apollo was the god of the sun, light, and creation.

Egyptians

As in all ancient civilizations, the gods of weather were very much a part of Egyptian life. Civilization extended along the banks of the Nile, where water was crucial for survival—that is, where cities, temples, pyramids, and the entire economic life of the kingdom were concentrated. The weather influenced the rising of the river and the harvests. Therefore the Egyptians venerated Re (the god of the sun), Nut (the god of heaven), Seth (the god of the storm), and Toth (the god of the moon).

RE
Egyptian sun god, the primordial creator. His center of worship was Heliopolis, or the City of the Sun.

SETH
Egyptian god of the storm, represented by a jackal, a dog, or a wolf. The son of Re and brother of Osiris.

Pre-Columbians

The pre-Columbian population believed water was a gift from the gods. For the Aztecs, Tlaloc was the god of rain, whereas the Incas called him Viracocha. Among the Mayans, he was known as Chac. He was the divinity of the peasants because water was the essential factor for stability and organization for these indigenous peoples. The calendar made it possible to forecast certain astrological events and rainstorms.

CHAC
Mayan god of agriculture. The Mayans performed ceremonies petitioning Chac for rain when drought threatened the harvest.

TLALOC
Venerated by the Aztecs, he was known as the provider because he had the power to bring rain, which made the corn grow.

VIRACOCHA
For the Incas, he was all powerful. Creator of the universe and of all the earth, he was linked with rays of light, thunder, lightning, and snow.

FUJIN
Japanese god of wind. Drawn as a dark monster, covered with leopard skin, he carried a bag of wind on his shoulders.

SURYA
Hindu god of the sun. In India the sun personified as Surya was considered to be harmful by the Dravidians of the south but benevolent by the peoples of central regions. These peoples attributed great healing power to the god.

The Orient

Hinduism has various weather-related gods. The most popular is Surya (god of the sun). Next come Chandra (god of the moon), Indra (the god who governs heaven), and Parjanya (god of rain). Japanese mythology emphasizes the following: Fujin (god of wind), Amaterasu (goddess of the sun), Tsukiyomi (god of the moon), Amatsu-kami (god of heaven), Susanoo (god of storms), and Aji-Suki-Taka-Hi-Kone (god of thunder).

Climate Zones

Different places in the world, even if far removed from each other, can be grouped into climate zones—that is, into regions that are homogeneous relative to climatic elements, such as temperature, pressure, rain, and humidity. There is some disagreement among climatologists about the number and description of each of these regions, but the illustrations given on this map are generally accepted.

Ice cap

Hudson Bay

NORTH AMERICA

Rocky Mountains

Appalachian Mountains

CENTRAL AMERICA

Pacific Ocean

Atlantic Ocean

SOUTH AMERICA

Cordillera de los Andes

Amazon basin

Pampas region

Patagonia

EUROPE

East European Plain

Alps

Black Sea

Caspian Sea

Siberia

Plains of Siberia

ASIA

Himalayas

Sahara

Arabian Peninsula

Congo basin

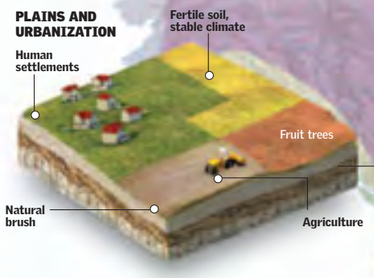
AFRICA

Indian Ocean

OCEANIA

Gibson Desert

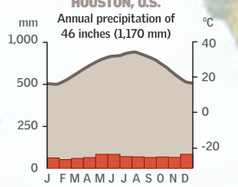
PLAINS AND URBANIZATION



TEMPERATE

Characterized by pleasant temperatures and moderate rains throughout the year. Winters are mild, with long, frost-free periods. Temperate regions are ideal for most agricultural products.

HOUSTON, U.S.
Annual precipitation of 46 inches (1,170 mm)

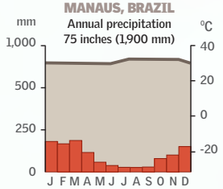


TROPICAL

High temperatures throughout the year, combined with heavy rains, are typical for this climate. About half of the world's population lives in regions with a tropical climate. Vegetation is abundant, and humidity is high because the water vapor in the air is not readily absorbed.

RAINFOREST OR JUNGLE

MANAUS, BRAZIL
Annual precipitation 75 inches (1,900 mm)



Temperature and Rains

The temperature of the Earth depends on the energy from the Sun, which is not distributed equally at all latitudes. Only 5 percent of sunlight reaches the surface at the poles, whereas this figure rises to 75 percent at the Equator. Rain is an atmospheric phenomenon. Clouds contain millions of drops of water, which collide to form larger drops. The size of the drops increases until they are too heavy to be supported by air currents, and they fall as rain.

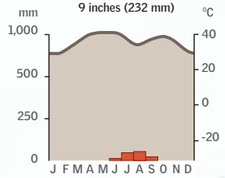
59° F (15° C)
is the average annual temperature of the Earth.

DESERT
Intermittent water

DRY

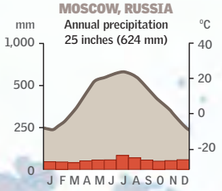
Lack of rain controls the arid climate in desert or semidesert regions, the result of the atmospheric circulation of air. In these regions, dry air descends, leaving the sky clear, with many hours of burning Sun.

TIMBUKTU, MALI
Annual precipitation 9 inches (232 mm)



FORESTS AND LAKES

MOSCOW, RUSSIA
Annual precipitation 25 inches (624 mm)



COLD

Very cold winters, with frequent freezing at night, are typical of these regions. In these zones, the climate changes more often than anywhere else. In most cold climate regions, the landscape is covered by natural vegetation.

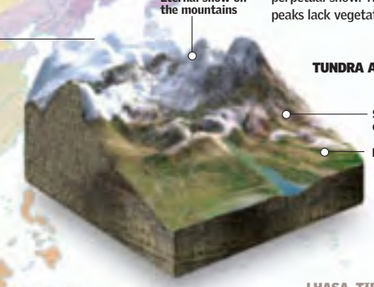
12° F (6.5° C)
is the temperature decrease for every 3,300 feet (1,000 m) of increase in elevation.

POLAR MOUNTAINOUS CLIMATE

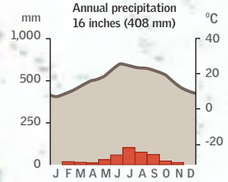
Mountains create their own climate that is somewhat independent of their location. Near the poles, the polar climate is dominated by very low temperatures, strong and irregular winds, and almost perpetual snow. The mountain peaks lack vegetation.

Eternal snow on the mountains

TUNDRA AND TAIGA

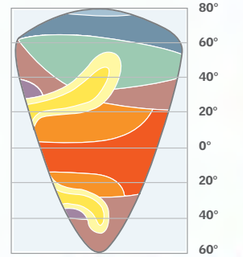


LHASA, TIBET
Annual precipitation 16 inches (408 mm)



Köppen Climate Classification

In 1936 Russian-born climatologist Wladimir Köppen presented a climatological classification based on temperature and precipitation. The table provides a broad overview of the approximate distribution of climates on the terrestrial globe. Köppen classification does not discuss climatic regions but rather the type of climate found in a given location according to specific parameters.



KEY

- Tropical forests, without a dry season
- Tropical savanna, with a dry winter
- Steppes (semiarid)
- Desert (arid)
- Temperate humid, without a dry season
- Temperate, with a dry winter
- Temperate, with a dry summer
- Tundra
- Glacial
- Mountain climate
- Temperate cold continental (hot summer)
- Temperate cold continental (cold summer)
- Temperate cold continental (subarctic)

Paleoclimatology

The climate of the planet is constantly changing. In approximately two million years, the Earth has gone through very cold periods, or glaciations, that lasted thousands of years, alternating with warm periods. Today we live in an interglacial period that began some 10,000 years ago with an increase in average global temperature. These climatic changes can be analyzed over time periods that exceed hundreds of thousands of years. Paleoclimatology uses records derived from fossils, tree rings, corals, glaciers, and historical documents to study the climates of the past.

VOSTOK

Latitude 77° S

Longitude 105° E

Surface area of the lake	**5,405 square miles (14,000 sq km)**
Inhabitants	**Only scientists**
Year of founding	**1957**
Temperature	**-67° F (-55° C)**
Surface	**95% ice**

Gas Measurement

Vertical ice cores (or samples) allow scientists to study the climate of the past. The nearly 12-foot-long (3.6-m) ice sample taken at the Russian Vostok station contains climatic data going back 420,000 years, including the concentration of carbon dioxide, methane, and other greenhouse gases in the atmosphere.

SAMPLES
The zones marked on the map are places where scientists have gathered samples of ice, which were analyzed in the laboratories.

KEY
- Drillings
- Ice sheets

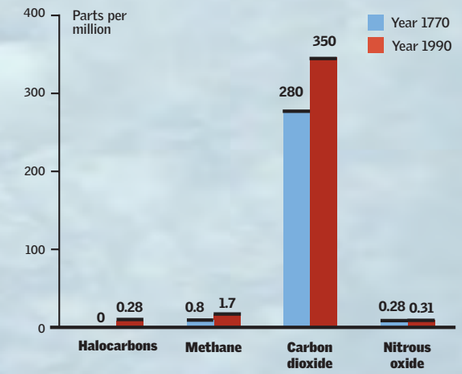
CLOTHES
protect the scientists from the weather and prevent the contamination of samples.

ICE CORES
Samples are taken at different depths. The surface snow becomes more compact in the lower layers. In the last layer, there are rocks and sand.

Human Activity

Climate can be divided into before and after the Industrial Revolution. This graphic shows the progressive increase of halocarbon gases, methane, carbon dioxide, and nitrous oxide between 1770 and 1990. It is clear that humans have contributed to the contamination of the planet.

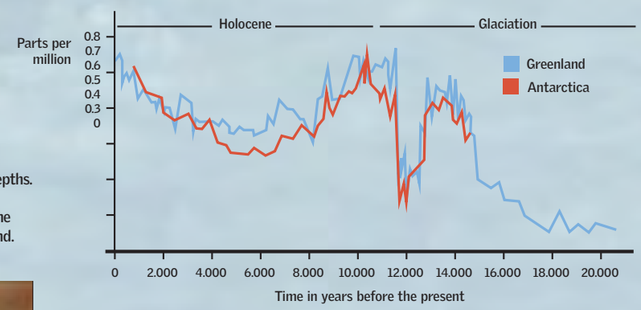
EVALUATION OF GREENHOUSE GASES



Composition

The lower graphic shows the change in concentration of methane in the atmosphere in the last 20,000 years until the end of the preindustrial era. The information collected was estimated on the basis of ice probes in Greenland and Antarctica.

METHANE CONCENTRATION



Chronology

During the history of the Earth, climate has changed greatly, which has had a large effect not only on the appearance of the Earth's surface but also on animal and plant life. This timeline shows the planet's major climate changes and their consequences.

B.Y.A. = billions of years ago M.Y.A. = millions of years ago Y.A. = years ago

4.5 B.Y.A.
In the beginning, there was heat. Life produces oxygen and cools the climate.

2.7-1.8 B.Y.A.
Ice covers very extensive areas.

544 M.Y.A.
Glacial climate in a changing geography. Extinction of 70 percent of marine species.

330 M.Y.A.
Beginning of a long period of glaciation. Ice covers different geographic areas.

245 M.Y.A.
Drought and heat at the beginning. Abrupt cooling at the end of the period. Appearance of the dinosaurs.

65 M.Y.A.
Paleocene and beginning Eocene: very warm climate. Middle Eocene: cooling begins.

2 M.Y.A.
The cold continues; glaciation occurs every 100,000 years.

1.6 M.Y.A.
Interglacial. The beginning of a two-million-year period.

18,000 Y.A.
begins the last deglaciation. Increase in temperature; melting of ice.

1,300-700 Y.A.
Medieval warm period; in some places warmer than today. Vikings arrive in Greenland..

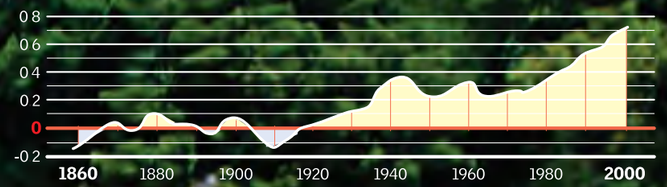
550-150 Y.A.
Little Ice Age. Alpine glaciers advance; more severe winters.

The Planet Warms Up

The increase in average temperature of the Earth's atmosphere and oceans is the result of global warming. The main cause is an increase in carbon dioxide emissions by industrialized nations during the past 200 years. This phenomenon has increased the greenhouse effect. It is estimated that the average global temperature has increased more than 1.1° F (0.6° C) between the end of the 19th century and the year 2000. The consequences of this are already beginning to be noticed. Changes are observed in the global distribution of precipitation: there are regions where there is an increase of rain, and there are other regions where rain is diminishing. This generates, among other things, a redistribution of fauna and flora, changes in ecosystems, and changes in human activities.

THE TEMPERATURE OF THE EARTH THROUGH THE YEARS

The effects of global warming are already noticeable. It is estimated that the average global temperature has increased more than 1.1° F (0.6° C) between the end of the 19th century and the year 2000.



GREAT BARRIER REEF

Latitude 18°S

Longitude 147°E

Surface	1,430 miles (2,300 km)
Types of reefs	3,000
Age	300 million years
Discovery	1770, by James Cook

Product of Human Activity

Our planet is going through an accelerated process of global warming because of the accumulation in the atmosphere of a series of gases generated by human activity. These gases not only absorb the energy emitted by the surface of the Earth when it is heated by radiation coming from the Sun, but they also strengthen the naturally occurring greenhouse effect, whose purpose is to trap heat. One of the primary agents responsible for the growth of the greenhouse effect is CO_2 (carbon dioxide), which is artificially produced by burning fossil fuels (coal, petroleum, and natural gas). Because of the intensive use of these fuels, there has been a notable increase in the quantity of both carbon and nitrogen oxides and carbon dioxide released into the atmosphere. Other aggravating human activities, such as deforestation, have limited the regenerative capacity of the atmosphere to eliminate carbon dioxide through photosynthesis. These changes have caused a slow increase in the average annual temperature of the Earth. Global warming, in turn, causes numerous environmental problems: desertification and droughts (which cause famines), deforestation (which further increases climate change), floods, and the destruction of ecosystems. Because all these variables contribute to global warming in complex ways, it is very difficult to predict with precision everything that will happen in the future.

84° F
(29° C)

The discoloration of coral occurs when the temperature exceeds 84° F (29° C). Algae are lost, the coral weakens, and the color of the coral fades.

1.1° F
(0.6° C)

APPROXIMATE INCREASE

Of the Earth's global average temperature from 1860

A Different World

With the changing patterns of precipitation and the shifting of air-pressure systems, some regions will become more humid, and others will suffer droughts. One of the areas that will become drier will be the western part of North America, where desertification is already affecting agriculture. According to current forecasts, areas in high latitudes, closer to the poles, will go through a rapid warming in the next 40 years. Populations of animals will be forced to emigrate from their habitat to avoid extinction, and other animals, such as the polar bear and emperor penguin, will have trouble subsisting as their habitats disappear. Ocean levels are rising between 0.4 and 0.8 inch (1 and 2 cm) per decade. Some Pacific island nations such as Tuvalu have contingency plans for evacuation. Another affected region is the Great Barrier Reef of Australia. The coral is very sensitive to changes in temperature. At temperatures above a normal 84° F [29 ° C], the coral begin to expel the algae on which they depend for food, and then they die.

Accelerated Melting

The climate is changing at a disconcerting speed. Glaciers are retreating, and sea level is rising because of a phenomenon known as thermal expansion. Scientists evaluating the planet's health deduce that this is the consequence of the Earth warming too rapidly. Human activity—in particular, the burning of fossil fuels and the consequent accumulation of greenhouse gases in the atmosphere—has increased this trend.

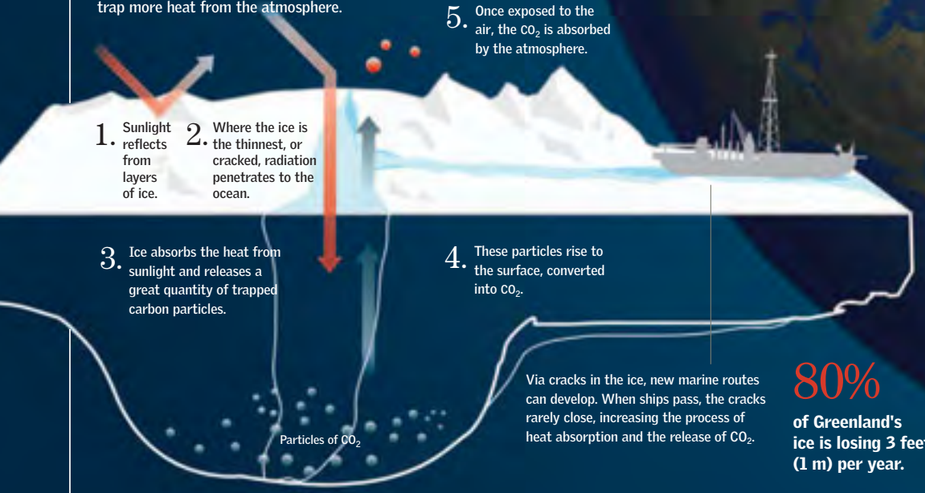
ARCTIC
Latitude 66° N
Longitude 0°

Surface area	5,444,040 square miles (14,100,000 sq km)
Depth	13,100 to 6,600 feet (4,000 to 2,000 m)
Temperature	-58° F (-50° C) in winter

Why It Happens

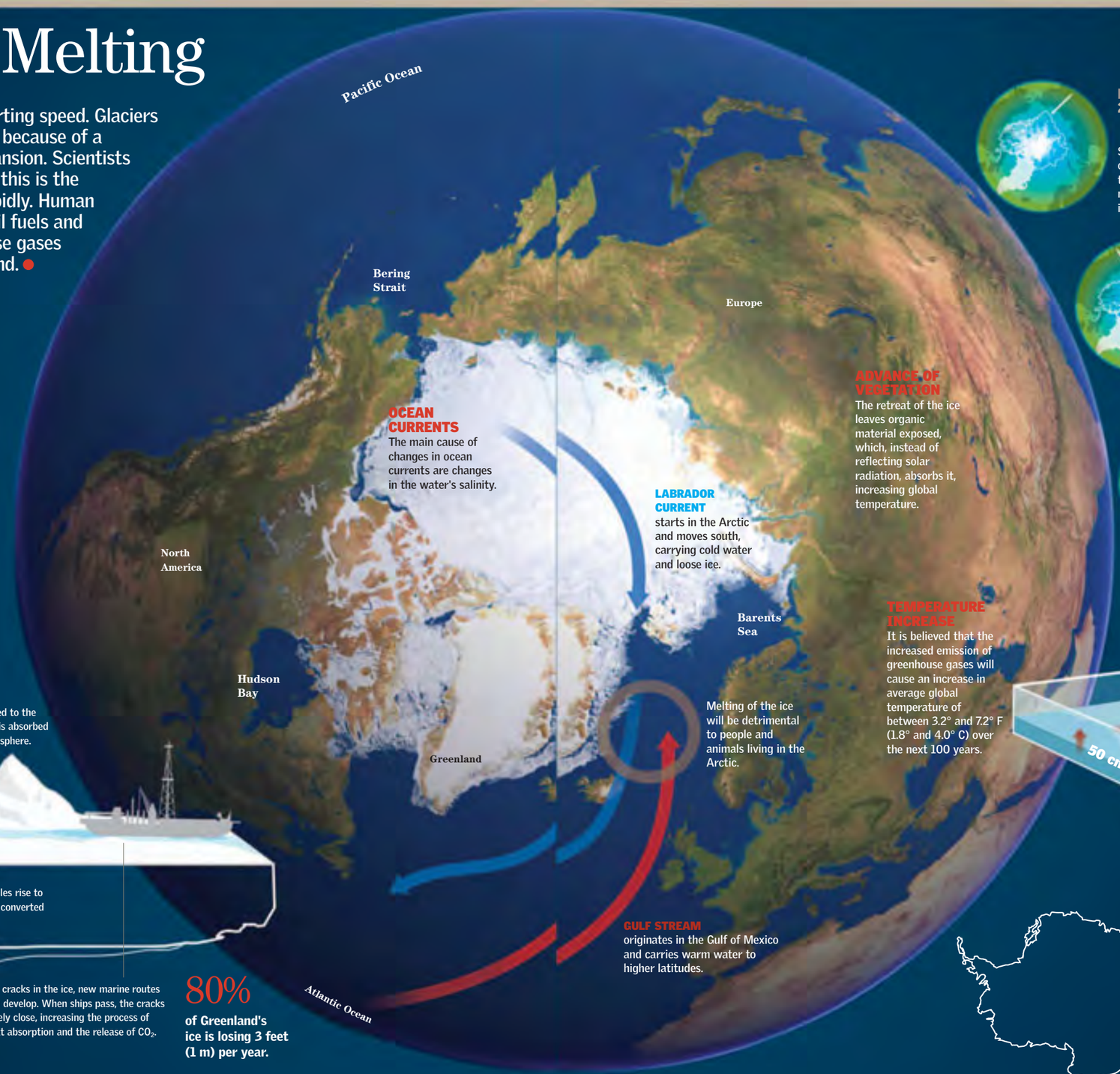
The thawing at the poles is, in part, caused by the increase of greenhouse gases. They absorb the radiation emitted by the Earth and heat up the atmosphere, further increasing the Earth's temperature. The melting of glaciers puts more water in the oceans.

EFFECT
The Arctic heats up more rapidly than the global average because of the darkness of the soil and the water, which, once exposed, trap more heat from the atmosphere.



Via cracks in the ice, new marine routes can develop. When ships pass, the cracks rarely close, increasing the process of heat absorption and the release of CO_2.

80%
of Greenland's ice is losing 3 feet (1 m) per year.



OCEAN CURRENTS
The main cause of changes in ocean currents are changes in the water's salinity.

LABRADOR CURRENT
starts in the Arctic and moves south, carrying cold water and loose ice.

GULF STREAM
originates in the Gulf of Mexico and carries warm water to higher latitudes.

Melting of the ice will be detrimental to people and animals living in the Arctic.

ADVANCE OF VEGETATION
The retreat of the ice leaves organic material exposed, which, instead of reflecting solar radiation, absorbs it, increasing global temperature.

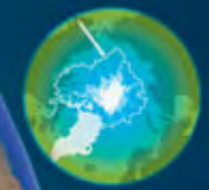
TEMPERATURE INCREASE
It is believed that the increased emission of greenhouse gases will cause an increase in average global temperature of between 3.2° and 7.2° F (1.8° and 4.0° C) over the next 100 years.

PROJECTIONS 2010-30

Summer sea ice, currently in decline, tends to diminish more and more rapidly in the future.

POSSIBLE FLOOD ZONES

In the period between 1993 and 2003, some coastlines were reduced by the rise in sea level.



2040-60

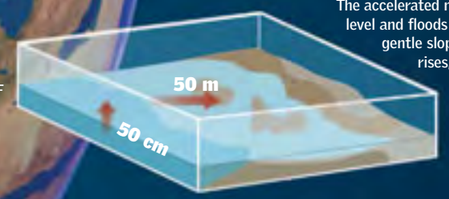
As the century progresses, sea ice continues to melt more and more along the coasts of the Arctic Ocean.

2070-90

Some scientific models project that summer sea ice will be virtually eliminated during this century.

ADVANCING WATERS

The accelerated melting raises sea level and floods coasts that have a gentle slope. As the sea level rises, the width of coastal areas diminishes.



164 feet (50 m)
The amount of coastal area lost when sea level rises 20 inches (50 cm)

70%
of the freshwater in the world is in Antarctica.

Antarctica

The Antarctic loses 36 cubic miles (152 cu km) of ice per year, and the western ice sheet is becoming thinner at an accelerating pace. This is contributing to increases in sea level. Over the long term, the effect on the climate could be disastrous for many regions of the planet.

Toxic Rain

Burning fossil fuel releases into the air chemicals that mix with water vapor and produce acid rain. The excess of sulfur dioxides and nitrogen dioxides in bodies of water makes the development of aquatic life more difficult, substantially increasing the mortality rate of fish. Likewise, it affects vegetation on land, causing significant damage in forested areas by contaminating animals and destroying substances vital for the soil. Moreover, acidic sedimentation can increase the levels of toxic metals, such as aluminum, copper, and mercury, that are deposited in untreated drinking-water reservoirs.

1 GAS EMISSIONS

Generated by burning fuels and the eruption of volcanoes

CO_2 SO_2 CH_4 H_2S CO NO_2

Petroleum refineries

Chemical industry

Waste incinerator

2 GAS MIXTURES

The molecules of various gases rise and mix with water in the air.

3 PHOTOCHEMICAL REACTION

Sunlight increases the speed at which chemical reactions occur. Thus, sulfur dioxide and atmospheric gases rapidly produce sulfur trioxide.

Atmospheric circulation enhances the dispersal of contaminants over great distances.

4 ACID RAIN

falls in the form of water, fog, or dew and leaves the acids formed in the atmosphere on the ground.

pH:5 Acid rain

pH:6 Normal rain

AREAS AFFECTED BY ACID RAIN

The regions most vulnerable to this phenomenon are Mexico, Beijing, Cairo, Jakarta (Indonesia), and Los Angeles.

WHAT IS pH?

pH acid

pH neutral

The degree of acidity of an aqueous solution. It indicates the concentration of hydrogen ions.

TYPES OF GASES EMITTED

Petroleum refinery	CO_2 (carbon dioxide) SO_2 (sulfur dioxide) CH_4 (methane)
Chemical industry	CO_2, SO_2, H_2S (hydrogen sulfide)
Waste incinerator	CO_2, SO_2, CH_4, CO (carbon monoxide) NO_2 (nitrogen dioxide)

CONSEQUENCES FOR PLANTS

Acid rain acts via certain mechanisms that weaken plants, making them more vulnerable to the effects of wind, cold, drought, disease, and parasites.

The leaves lose their wax layer.

Destruction of chlorophyll

Defoliation

Root damage

MOST-THREATENED SPECIES

Fir Beech Oak

LEAVES
This rain damages their surface, causing small lesions that alter the action of photosynthesis.

CONSEQUENCES FOR AGRICULTURE

Areas under cultivation are not as vulnerable because they are generally improved by fertilizers that restore nutrients to the soil and neutralize acidity.

Seriously affected species are lettuce and tobacco, especially because their leaves, destined for human consumption, must be of high quality.

Melting water carries acidic particles that come from the rain.

EFFECTS ON THE WATER

The acidity of rainwater changes the neutral pH of bodies of water.

pH 7 (neutral) → pH 4.3 (acid)

pH 4.3 LEVEL AT WHICH FISH DO NOT SURVIVE IN THE WATER

SOIL CONSEQUENCES

SILICATE SOIL
The effect of acidity increases because of the lack of buffering minerals.

CALCAREOUS SOIL
The effect is neutralized by the presence of bicarbonate.

In mountainous areas, fog and snow contribute significant quantities of the gases in question.

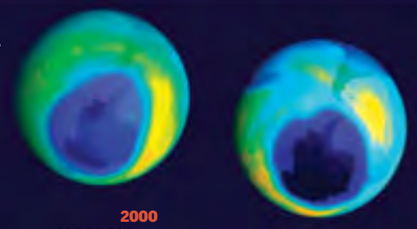
1972 The year when the phenomenon of acid rain was recorded for the first time

MOST-AFFECTED SPECIES

Trout Perch Frogs

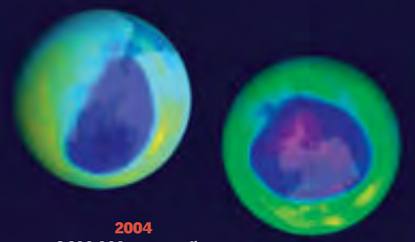
Weaker and Weaker

Artificial substances are destroying the ozone layer, which provides protection against ultraviolet rays. This phenomenon is observed every year in polar regions (primarily in the Antarctic) between August and October. Because of this, the Earth is receiving more harmful rays, which perhaps explains the appearance of certain illnesses: an increase in skin cancer cases, damage to vision, and weakening of the immune system.



2000
11,000,000 square miles
(28,000,000 sq km)

2001
10,000,000 square miles
(26,000,000 sq km)



2004
9,300,000 square miles
(24,200,000 sq km)

2005
10,400,000 square miles
(27,000,000 sq km)

THE SOUTHERN OZONE HOLE

The thinning of the ozone layer over the Antarctic is the result of a series of phenomena, including the action of chlorine radicals, which cause the destruction of ozone.

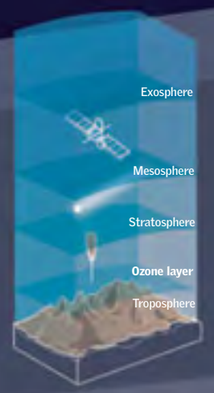
UV RADIATION

Ultraviolet radiation (UV) is a radiant form of energy that comes from the Sun. The various forms of radiation are classified according to the average wavelength measured in nanometers (nm), equivalent to one millionth of a millimeter. The shorter the wavelength, the greater the energy of the radiation.

UV-A
These rays easily penetrate the ozone layer. They cause skin wrinkling and aging.

UV-B
are almost all absorbed by the ozone layer. They are harmful and cause various types of skin cancer.

UV-C
These are the most damaging rays, but they are totally filtered by the upper part of the ozone layer.



OZONE LAYER

At an altitude of 12 to 19 miles (20 to 30 km), the Earth is surrounded by a stratospheric ozone layer that is of vital importance for life on the surface. The layer is formed from oxygen molecules through the absorption of ultraviolet light from the Sun. This reaction is reversible, that is, the ozone can return to its natural state, oxygen. This oxygen is reconverted into ozone, beginning a continuous process of formation and destruction of these components.

It is popularly called the ozone hole—a decrease or abnormal thinning that occurs in the ozone layer.

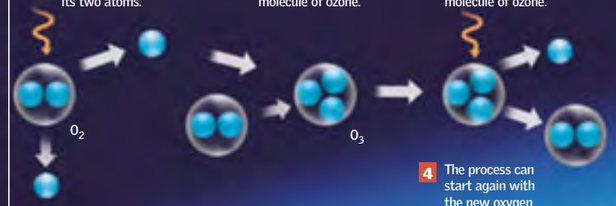
11,000,000 square miles (28,000,000 sq km)
is the size of the area of attenuated ozone reached in 2000.

The ozone layer functions as a natural filter, absorbing UV rays.

75%
OF SKIN CANCER IS ATTRIBUTED TO UV-B RADIATION.

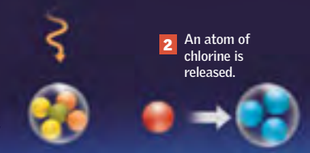
HOW OZONE IS FORMED

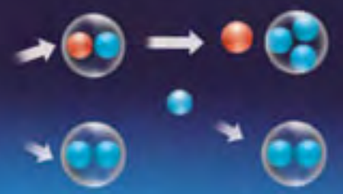
1. Ultraviolet rays strike a molecule of oxygen which breaks up and releases its two atoms.
2. One of the released atoms combines with a molecule of oxygen. Together they form a molecule of ozone.
3. One of the released atoms combines with a molecule of oxygen. Together they form a molecule of ozone.
4. The process can start again with the new oxygen molecule.



HOW IT DETERIORATES

1. Ultraviolet radiation strikes a molecule of CFC gas.
2. An atom of chlorine is released.
3. Chlorine atoms combine with a molecule of ozone, destroy it, and form one chloromonoxide and one oxygen atom.
4. The chloromonoxide combines with an atom of free oxygen and releases the chlorine atom.
5. This atom, once again free, combines with another molecule of ozone.





CFC GASES

are a family of gases with multiple applications. They are used in refrigeration systems, air-conditioning equipment, and aerosols.

50 to 100
THE NUMBER OF YEARS THAT CFC GASES SURVIVE IN THE ATMOSPHERE

WHEN? WHO? HOW?

In 1974, it was discovered that industrial chlorofluorocarbons (CFCs) affect the ozone layer. Chemists Mario Molina and F. Sherwood Rowland demonstrated that industrial CFCs are the gases that weaken the ozone layer by destroying the ozone molecules.

HUMAN BEINGS

Skin cancer. Damage to vision. Weakening of the immune system. Severe burns. Skin aging.

PLANTS

Destruction of phytoplankton. Inhibition of the photosynthesis process. Changes in growth. Reduced harvest yields.

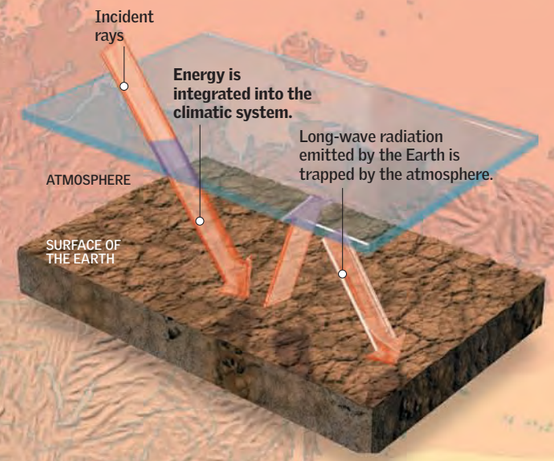
ANIMALS

Diseases among farm animals. Destruction of links in the food chain. Increase of skin cancer.

Change; Everything Changes

The Most Responsible

The climate of the planet is constantly changing. At present, the average global temperature is approximately 59° F (15° C). Geologic and other types of evidence suggest that in the past the average could have been as low as 45° F (7° C) and as high as 81° F (27° C). Climate change is, in large part, caused by human activities, which cause an increase in the concentration of greenhouse gases. These gases include carbon dioxide, methane, and nitrogen dioxide and are released by modern industry, by agriculture, and by the burning of coal, petroleum, and natural gas. Its atmospheric concentration is increasing: atmospheric carbon-dioxide content alone has grown by more than 20 percent since 1960. Investigators indicate that this warming can have grave implications for the stability of the climate, on which most of the life on the planet depends.



ACCELERATION OF THE GREENHOUSE EFFECT

Ice reflects solar radiation, whereas the soil of jungles, forests, and steppes absorbs the energy and radiates it as sensible heat. This artificially increases the greenhouse effect and contributes to global warming.

NORTH AMERICA

CENTRAL AMERICA

SOUTH AMERICA

EUROPE

ASIA

AFRICA

OCEANIA

Atlantic Ocean

Pacific Ocean

Indian Ocean

More than 10.8° F (6° C)

From 9° to 10.8° F (5° to 6° C)

From 7.2° to 9° F (4° to 5° C)

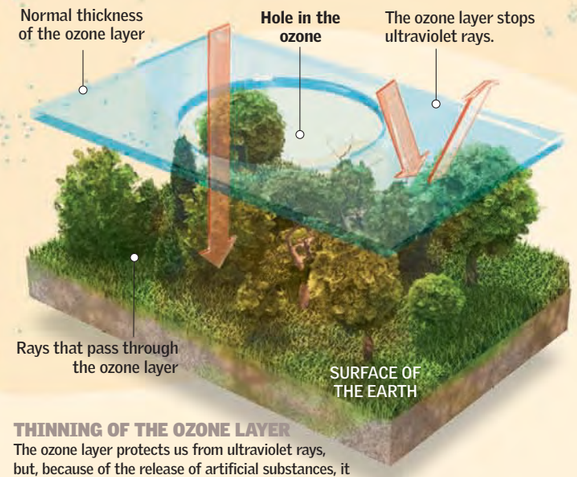
From 5.4° to 7.2° F (3° to 4° C)

From 3.6° to 5.4° F (2° to 3° C)

From 1.8° to 3.6° F (1° to 2° C)

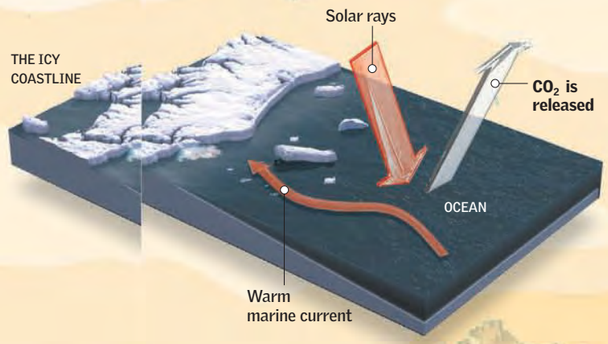
THE RISE IN TEMPERATURE

In Alaska and western Canada winter temperatures have increased between 5.4° and 7.2° F (3° and 4° C) in the past 50 years. It has been projected that in the next 100 years the Earth's average temperature will increase between 3.2° and 7.2° F (1.8° and 4.0° C).



THINNING OF THE OZONE LAYER

The ozone layer protects us from ultraviolet rays, but, because of the release of artificial substances, it is thinning out. This phenomenon is observed each year over Antarctica between August and October and over the North Pole between October and May. Moreover, there is evidence that greater amounts of UV rays at the Earth's surface are destroying or altering vegetable cells and decreasing the production of oxygen.



THE EFFECT OF POLAR MELTING

The snow-covered sea ice reflects between 85 and 90 percent of the sunlight that strikes it, whereas sea water reflects only 10 percent. For that reason, as the ice and snow melt, many of today's coastlines will become submerged under water, which will cause yet more ice to melt.

Cause and Effect

The burning of fossil fuels and the indiscriminate cutting of deciduous forests and rainforests cause an increase in the concentration of carbon dioxide, methane, and other greenhouse gases. They trap heat and increase the greenhouse effect. That is how the Arctic is warming up; the density of the ice is decreased by melting, and freshwater flows into the ocean, changing its salinity.

100 years is the length of time it takes for a deciduous forest to return to its natural state after it has been laid to waste.

Glossary

Accretion

Growth of an ice crystal in the atmosphere by direct capture of water droplets when the temperature is below 32° F (0° C).

Acid Rain

Rain resulting from the mixture of water vapor in the air with chemical substances typically released by the combustion of fossil fuels.

Aerosol

Aerosols are very small (liquid or solid) particles suspended in the atmosphere, with varied chemical composition. Aerosols play an essential role in the formation of clouds by acting as condensation nuclei. They are also important to the Earth's radiation balance since they help to increase the reflection and dispersion of radiation coming from the Sun.

Air Mass

Extensive volume in the atmosphere whose physical properties, in particular the temperature and humidity in a horizontal plane, show only small and gradual differences. An air mass can cover an area of a few million square miles and can have a thickness of several miles.

Albedo

A measure of the percentage of radiation reflected by a surface.

Altitude

Height relative to sea level.

Anemometer

Instrument for measuring wind velocity.

Anticyclone

Region where the atmospheric pressure is relatively high compared with neighboring regions. Normally the air above an anticyclone descends, which prevents clouds from forming at medium and high levels of the atmosphere. Hence an anticyclonic system is associated with good weather.

Atmosphere

The gaseous envelope that surrounds the Earth.

Atmospheric Pressure

The pressure or weight exerted by the atmosphere at a specific point. Its measurement can be expressed in various units: hectopascals, millibars, inches, or millimeters of mercury (Hg). It is also called barometric pressure.

Aurora

A phenomenon that is produced in the higher layers of the atmosphere at polar latitudes. An aurora occurs when there is a collision between the electrically charged particles emitted by the Sun and the magnetic field of the Earth. In the Northern Hemisphere, the phenomenon is called the aurora borealis, and in the Southern Hemisphere, it is known as the aurora australis.

Avalanche

A large mass of snow that flows down the side of a mountain.

Barometer

An instrument for measuring atmospheric pressure. A decrease in pressure usually means that storms are on the way. Increasing pressure indicates good weather.

Beaufort Scale

A scale invented at the beginning of the 19th century by a British sailor, Francis Beaufort, for estimating and reporting wind velocity. It is based on the different shapes taken by water waves at different wind velocities, and its graduation goes from 0 to 12. There is also a Beaufort scale for application on land based on observations of the wind's effect on trees and other objects.

Carbon Dioxide

An odorless, colorless gas emitted in the engine exhaust of automobiles, trucks, and buses. It is also produced by the combustion of coal and other organic material. Too much carbon dioxide in the atmosphere contributes to global warming.

Chlorofluorocarbons

Artificial chemical substances often contained in aerosols, refrigerants, and air conditioners. These chemicals are largely responsible for the damage to the ozone layer.

Cirrus

Wispy cloud formations at altitudes greater than 16,400 feet (5,000 m).

Climate

The average state of the meteorological conditions of a location considered over a long period of time. The climate of a location is determined by climatological factors: latitude, longitude, altitude, topography, and continentality.

Cloud

A visible mass of small particles, such as droplets of water and/or crystals of ice, suspended in the air. A cloud is formed in the atmosphere because of the condensation of water vapor onto solid particles of smoke, dust, ashes, and other elements called condensation nuclei.

Coalescence

The process of growth of drops of water in a cloud. Two drops collide and remain joined after the collision, constituting a bigger drop. This is one of the mechanisms that explains the growth of the size of drops in a cloud until precipitation (rain) is produced.

Cold Wave

A rapid drop in temperature to the point requiring special protective measures in agriculture, industry, commerce, or social activities.

Condensation

The process by which water vapor is transformed into liquid by the effect of cooling.

Conduction

The transfer of heat through a substance by molecular action or from one substance to another it is in contact with.

Continentality

The tendency of the interior regions of the continents to have more extreme temperature changes than coastal zones.

Convection

The process by which a heated surface transfers energy to the material (air, water, etc.) above it. This material becomes less dense and rises. Cooler material descends to fill in the void. Air rising as a result of the heating of the ground by the Sun's rays.

Coriolis Force

A fictitious or apparent force that applies when the Earth is used as a reference frame for motion. It depends upon the latitude and the velocity of the object in motion. In the Northern Hemisphere, the air is deflected toward the right side of its path, and in the Southern Hemisphere, the air is deflected toward the left side of its path. This force is strongest at the poles and does not exist at the Equator.

Cyclone

A climatic low-pressure system.

Desert

A hot or cold zone where annual precipitation is less than 1 inch (25 mm).

Desertification

A process that converts fertile land to desert through a reduction in precipitation.

Dew

Condensation in the form of small drops of water formed on grass and other small objects near the ground when the temperature has dropped to the dew point. This generally happens during the night.

Dike

An earthwork for containing or channeling a river or for protection against the sea.

Drizzle

A type of light liquid precipitation composed of small drops with diameters between 0.007 and 0.019 inch (0.2 and 0.5 mm). Usually drizzle falls from stratus-type clouds that are found at low altitudes and can be accompanied by fog, which significantly decreases visibility.

Drought

An abnormally dry climatic condition in a specific area where the lack of water is prolonged and which causes a serious hydrological imbalance.

El Niño

The anomalous appearance, every few years, of unusually warm ocean conditions along the tropical west coast of South America.

Erosion

Action in which the ground is worn down by moving water, glaciers, wind, or waves.

Evaporation

Physical process by which a liquid (such as water) is transformed into its gaseous state (such as water vapor). The reverse process is called condensation.

Exosphere

The outermost layer of the Earth's atmosphere.

Flash Flood

Sudden flooding caused by the passage of a large quantity of water through a narrow space, such as a canyon or a valley.

Fog

Visible manifestation of drops of water suspended in the atmosphere at or near ground level; this reduces the horizontal visibility to less than a mile. It originates when the temperature of the air is near the dew point, and sufficient numbers of condensation nuclei are present.

Forecast

A statement about future events. The weather forecast includes the use of objective models based on a number of atmospheric parameters combined with the ability and experience of the meteorologist. It is also called weather prediction.

Front

The transition or contact zone between two masses of air with different meteorological characteristics, which almost always implies different temperatures. For example, a front occurs at the area of convergence between warm humid air and dry cold air.

Frontogenesis

The process of formation or intensification of a front. This happens when wind forces two adjacent masses of air of different densities and temperatures together, creating a front. It can occur when one of the masses of air, or both, move over a surface that reinforces their original properties. This is common on the east coast of North America or Asia, when a mass of air moving toward the ocean has a weak or undefined boundary. It is the opposite of frontolysis.

Frost

A covering of ice crystals on a cold object.

Global Warming

The heating of the atmosphere caused by increased concentrations of greenhouse gases due to human activities.

Greenhouse Effect

A phenomenon explained by the presence of certain components in the atmosphere (primarily carbon dioxide [CO_2], water vapor, and ozone) that absorb a portion of the infrared radiation emitted by the surface of the Earth and simultaneously reflect radiative energy back to the surface. This process contributes to the increase in the average temperature near the surface.

Gust

A rapid and significant increase in wind velocity. The maximum velocity of the wind must reach at least 16 knots (18 miles per hour [30 km/h]), and the difference between the peaks and calm must be at least 10 knots (12 miles per hour [18 km/h]). It generally lasts less than 20 seconds.

Hail

Precipitation that originates in convective clouds, such as the cumulonimbus, in the form of masses or irregular pieces of ice. Typically hail has a diameter of 0.2 to 2 inches (5 to 50 mm) but may grow significantly larger. The smallest ice fragments—whose diameter is 0.2 inch (5 mm) or less—are called small hailstones, or graupel. Strong upward currents are required inside the clouds for hail to be produced.

Heat Wave

A period of abnormally hot and uncomfortable weather. It can last from a few days to a number of weeks.

Hectopascal

A pressure unit equal to 100 pascals and equivalent to 1 millibar—a millibar being equivalent to 0.031 inch (0.8 mm) of ordinary mercury. The millibar (mb) was the technical unit used to measure pressure until recently, when the hectopascal was adopted. The pascal is the unit for pressure in the MKS system, corresponding to the pressure exerted by the unit force (1 newton) on a unit surface (1 square meter—11 square feet); 1,000 hPa = 1,000 mb = 1 bar = 14.5 pounds per square inch.

High

A prefix describing cloud formations at an altitude between 6,560 and 16,400 feet (2,000 and 5,000 m).

Humidity

The amount of water vapor contained in the air.

Hurricane

The name for a tropical cyclone with sustained winds of 64 knots (74 miles per hour [119 km/h]) or more, which develops in the North Atlantic, the Caribbean, the Gulf of Mexico, and the Pacific Northeast. This storm is called a typhoon in the western Pacific and a cyclone in the Indian Ocean.

Hygrometer

An instrument used to measure humidity.

Ice

The solid state of water. It is found in the atmosphere in the form of ice crystals, snow, or hail.

Jet Streams

Air currents high in the troposphere (about 6 miles [10 km] above sea level), where the wind velocity can be up to 90 meters per second (200 miles per hour). This type of structure is seen in subtropical latitudes in both hemispheres, where the flow is toward the east, reaching its maximum intensity during the winter.

Latitude

A system of imaginary parallel lines that encircle the globe north and south of the Equator. The poles are located at 90° latitude north and south and the Equator at 0° latitude.

Lightning

A discharge of the atmosphere's static electricity occurring between a cloud and the ground.

Mesosphere

The layer of the Earth's atmosphere that lies above the stratosphere.

METAR

The name of the format airport meteorological bulletins are reported in. This includes data on wind, visibility, temperature, dew point, and atmospheric pressure, among other variables.

Meteorology

The science and study of atmospheric phenomena. Some of the subdivisions of meteorology are agrometeorology, climatology, hydrometeorology, and physical, dynamic, and synoptic meteorology.

Microbarometer

A very sensitive barometer that records pressure variations using a magnified scale.

Mist

Microscopic drops of water suspended in the air, or humid hygroscopic particles, which reduce visibility at ground level.

Monsoon

A seasonal wind that causes heavy rains in tropical and subtropical regions.

Normal

The standard value accepted for a meteorological element as calculated for a specific location over a specific number of years. The normal values refer to the distribution of data within the limits of the common occurrence. The parameters can include temperature (high, low, and divergences), pressure, precipitation (rain, snow, etc.), winds (velocity and direction), storms, cloud cover, percentage of relative humidity, and so on.

Ocean Current

The movement of water in the ocean caused by the system of planetary winds. Ocean currents transport warm or cold water over long distances around the planet.

Orographic Rain

Rain that results from the cooling of humid air as it crosses over a mountain range.

Ozone Layer

A layer of the atmosphere situated 20 to 30 miles (30 to 50 km) above the Earth's surface between the troposphere and the stratosphere. It acts as a filtering mechanism for ultraviolet radiation.

Polar Front

An almost permanent and very large front of the middle latitudes that separates the relatively cold polar air and the relatively warm subtropical air.

Precipitation

A liquid or solid, crystallized or amorphous particle that falls from a cloud or system of clouds and reaches the ground.

Radiation

The process by which energy propagates through a specific medium (or a vacuum) via wave phenomena or motion. Electromagnetic radiation, which emits heat and light, is one form of radiation. Other forms are sound waves.

Seaquake

An earthquake at the bottom of the ocean, causing a violent agitation of ocean waves, which in some cases reach coastal areas and cause flooding.

Snow

Precipitation in the form of white or transparent frozen ice crystals, often in the form of complex hexagons. In general, snow falls from stratiform clouds, but it can also fall from cumulus clouds, usually in the form of snowflakes.

Stratosphere

The layer of the atmosphere situated above the troposphere.

Stratus

Low clouds that form layers. They often produce drizzle.

Synoptic Map

A map that shows weather conditions of the Earth's surface at a certain time and place.

Thermal Inversion

An inversion of the normal reduction in temperature with an increase in altitude.

Thermometer

An instrument for measuring temperature. The different scales used in meteorology are Celsius, Fahrenheit, and Kelvin (or absolute).

Tornado

A column of air that rotates with great violence, stretching between a convective cloud and the surface of the Earth. It is the most destructive phenomenon in the atmosphere. Tornadoes can occur, under the right conditions, anywhere on Earth, but they appear most frequently in the central United States, between the Rocky Mountains and the Appalachian Mountains.

Tropical Cyclone

A cyclone without fronts, it develops over tropical waters and has a surface circulation organized and defined in a counterclockwise direction. A cyclone is classified, according to the intensity of its winds, as a tropical disturbance (light ground-level winds), tropical depression (maximum ground-level winds of 38 miles per hour [61 km/h]), tropical storm (maximum winds in the range of 39 to 73 miles per hour [62 to 112 km/h]), or hurricane (maximum ground-level winds exceeding 74 miles per hour [119 km/h]).

Troposphere

The layer of the atmosphere closest to the ground, its name means "changing sphere," and this layer is where most changes in weather take place. This is also where most of the phenomena of interest in meteorology occur.

Turbulence

Disorderly motion of air composed of small whirlwinds that move within air currents. Atmospheric turbulence is produced by air in a state of continuous change. It can be caused by thermal or convective currents, by differences in terrain and in the velocity of the wind, by conditions along a frontal zone, or by a change in temperature and pressure.

Weather

The state of the atmosphere at a given moment, as it relates to its effects on human activity. This process involves short-term changes in the atmosphere in contrast to the great climatic changes that imply more long-term changes. The terms used to define weather include cloudiness, humidity, precipitation, temperature, visibility, and wind.

Windward

The direction from which the wind is blowing.

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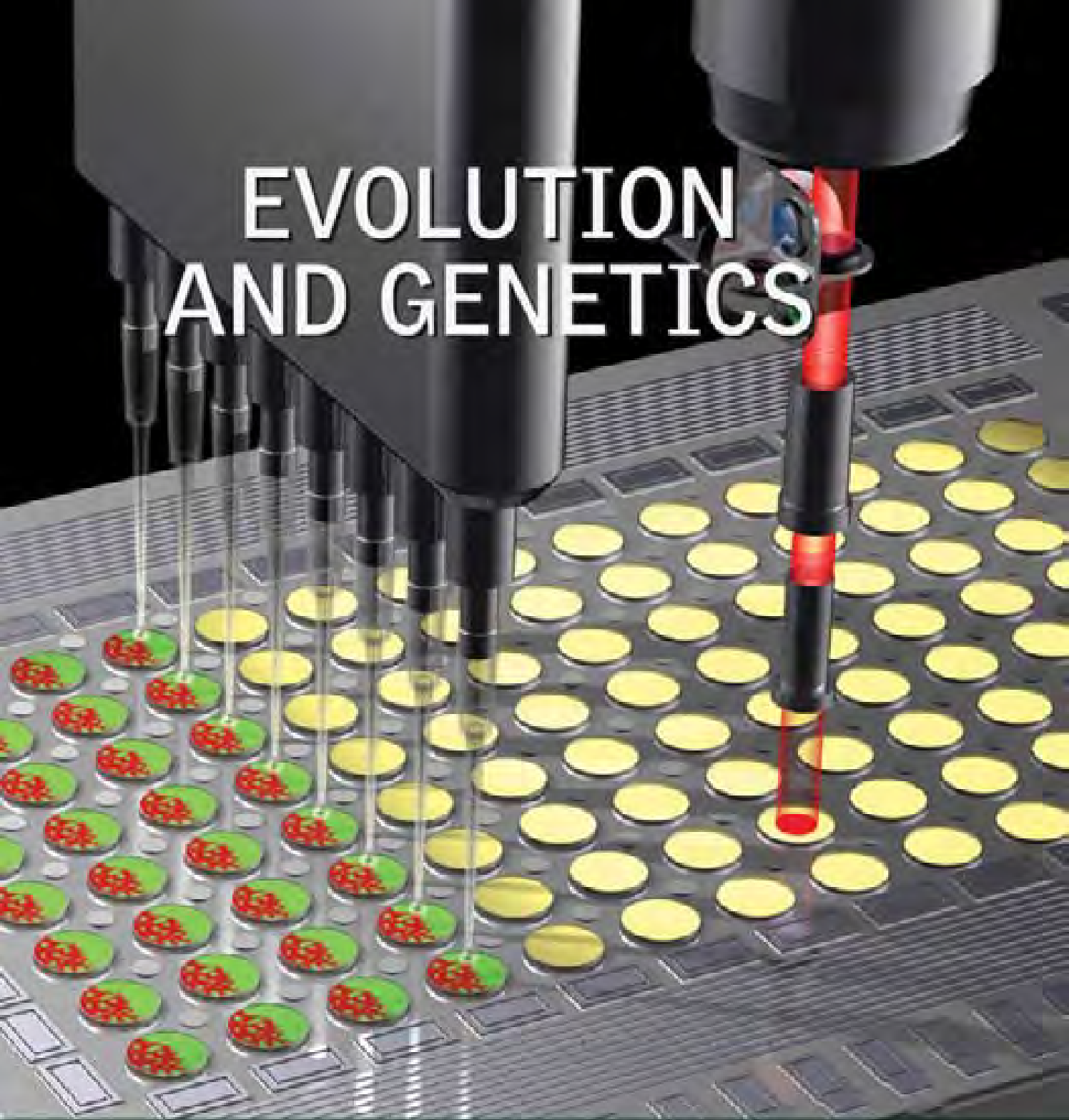

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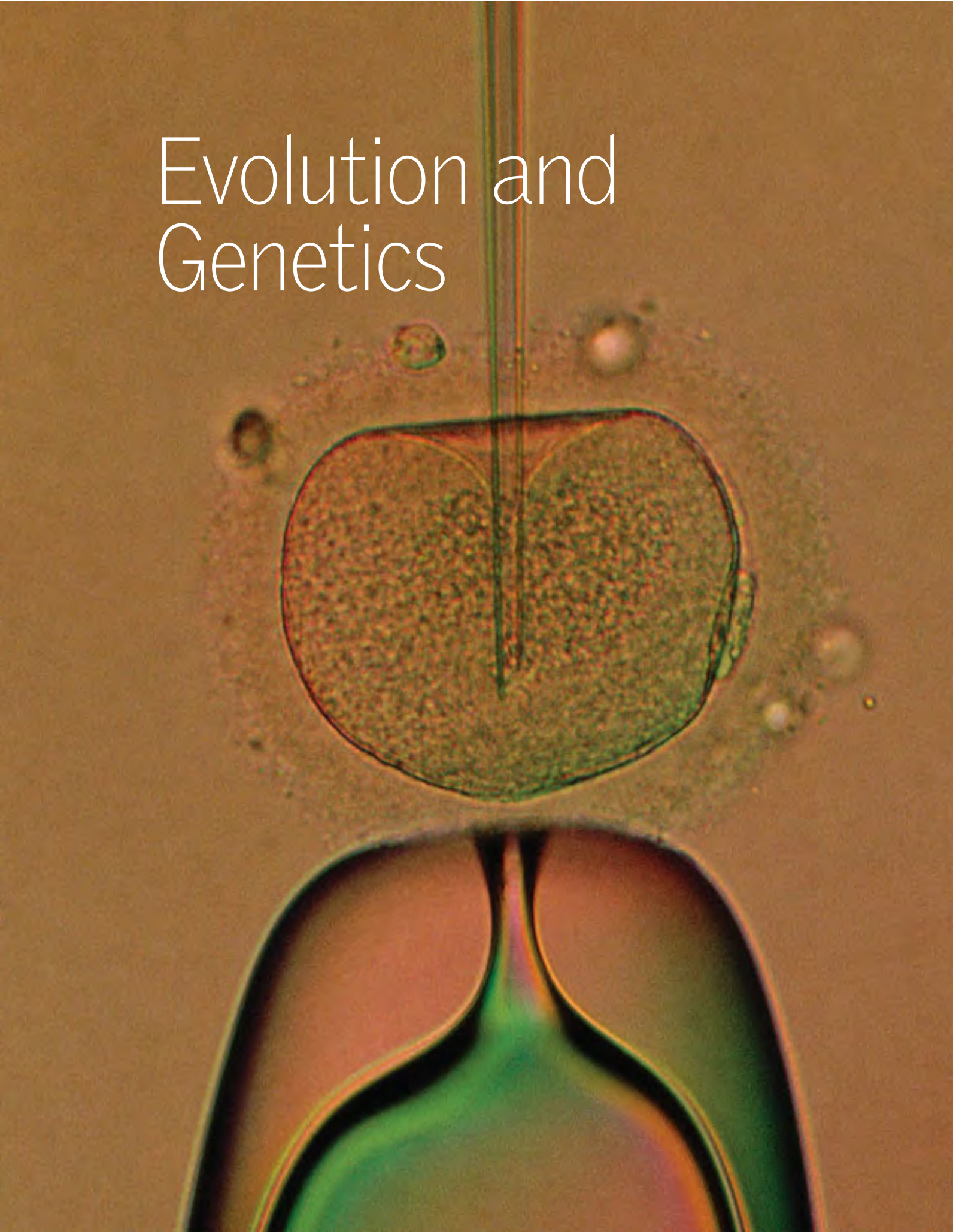

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In vitro fertilization. The image shows the moment at which the sperm DNA is injected into an ovule.

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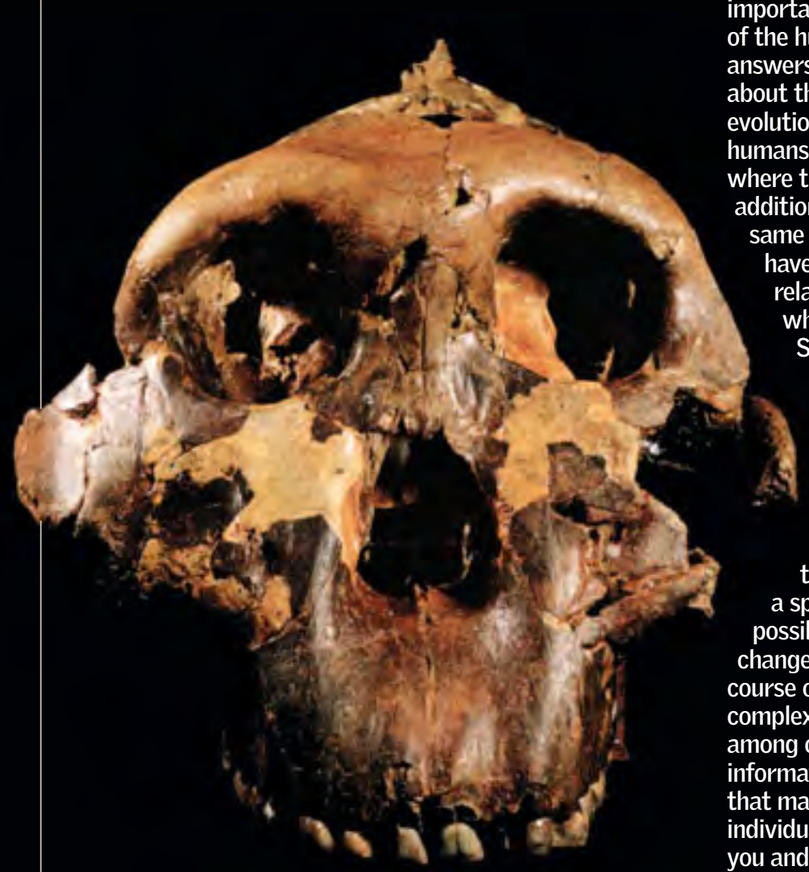
Yesterday, Today, and Tomorrow

FACES OF THE PAST
The skull of Australopithecus (below) shows a reduced cerebral portion and a strong jaw. To the right, Cro-Magnon, a representative of modern humans, exhibits a more evolved skull with greater cerebral capacity.



When did humans appear? What is it that makes us different from the rest of the animals? In what way did language develop? Why is it so important to have deciphered the sequence of the human genome? This book offers answers to these and many other questions about the mysteries and marvels of human evolution. Scientists maintain that modern humans originated in Africa because that is where they have found the oldest bones. In addition, genetics has just arrived at the same conclusion, since the DNA studies have confirmed that all humans are related to the African hunter-gatherers who lived some 150 million years ago. Studying the fossils, the experts also found that human skulls from two million years ago already show the development of two specific protuberances that in the present-day brain control speech, the capability that perhaps was as important for early humans as the ability to sharpen a rock or throw a spear. Today thanks to science it is possible to affirm that the brain has changed drastically in the evolutionary course of the species, reaching a greater complexity in humans. This has facilitated, among other things, the capacity to store information and the flexibility in behavior that makes a human an incredibly complex individual. The purpose of this book is to tell you and show you in marvelous images many of the answers that people have found throughout history, through their successes, failures, and new questions. These new questions have served to shape the world in which we live, a world whose scientific, technological, artistic, and industrial development surprises and at times frightens us. History is full of leaps. For thousands of years nothing may happen, until all of a sudden some new turn or discovery gives an impulse to humankind. For example, with the domestication of animals and the cultivation of plants, a profound societal revolution occurred. This period of prehistory, called the Neolithic, which dates to 10 million years ago, opened the way for the development of civilization. With the possibility of obtaining food without moving from place to place, the first villages were established and produced great demographic growth.

The book that you have in your hands explains all this in an accessible way. Here you will also find information about the latest discoveries related to the structure of DNA, the molecule of heredity, that opens new areas of investigation. It contributes to the study of clinical and forensic medicine and posits new questions about the origin of life and where we are headed as humans. The possibility of untangling the sequence of the human genome is not only important in trying to explain why we are here and to explore our evolutionary past, but it also offers the possibility of altering our future. In the decades to come, the application of genetic therapy will allow, among other things, the cure of genetic disorders caused by defective genes. In addition, the alternative of knowing beforehand what diseases a person could develop will be extremely valuable in the field of health, because we will be able to choose examinations and treatments according to individual needs. Another very promising area of medical research involves the use of stem cells that have the unique capacity to be used at some future date to regenerate organs or damaged tissues.
Do not wait any longer. Turn the page and begin to enjoy this book, which may be a point of departure in your own adventure in learning. ●

Myths and Scientific Evidence

BLACK SHEEP
The black color of this specimen is a clear expression of genes, the function of which is to determine different traits.

VARIOUS BELIEFS 8-9
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TO LIVE OR DIE 14-15
THE CRITICAL POINT 16-17

The evolution of species cannot be considered an isolated event in itself but rather the result of a complex and constant interaction among different elements. It represents not simply an unlimited number of genetic mutations but also changes in the environment, fluctuations in sea level, varying contributions of nutrients, and possibly factors such as the reversal of the Earth's magnetic field or the impact of large meteorites on the Earth's surface. In this chapter, we tell you stories and legends from some of the most remote places in the world as well as various scientific theories concerning the origin of life and of human beings. Some of the curious facts and photos in these pages will surprise you. ●

Various Beliefs

Before the emergence of scientific theories, most people in the world had their own versions of the origin of the world and of humankind expressed primarily in the form of myths. Many of them have reached us through the teachings of different religions. In many cases, the origin of the world and of humankind relates to one or several creator gods or demigods; in other cases, there is no beginning and no end. With regard to the origin of the human race (the word "human" shares the same root as the Latin word *humus*, meaning "earth"), there is a Central African legend that links humans to monkeys.

The Matter of Creation

India is a multicultural, agricultural society where much of its thousand-year-old rituals still exist. However, its sacred texts were written at very different times, from 1,000 BC (the Rigveda) to the 16th century AD (the Puranas), and they offer different versions of the origin of humankind. One of them even tells of a primal man (Purusha) from whom gods originated and from whose body parts the different castes arose. In this culture, social classes are strongly differentiated.

BRAHMA, THE CREATOR
Another version states that the first human emerged directly from the god Brahma, whose human image is represented by this statue.

HERMAPHRODITE
According to more recent texts (from the 15th century), the first person Brahma created was called Manu, and he was a hermaphrodite. The story goes that as a result of his dual sexual condition, he had a number of children, both males and females.

PROPORTION
The size of the heads reveals the importance given to the symbols.

YORUBA MASK
represents the two sexes.

Africa: How Monkeys Became Human

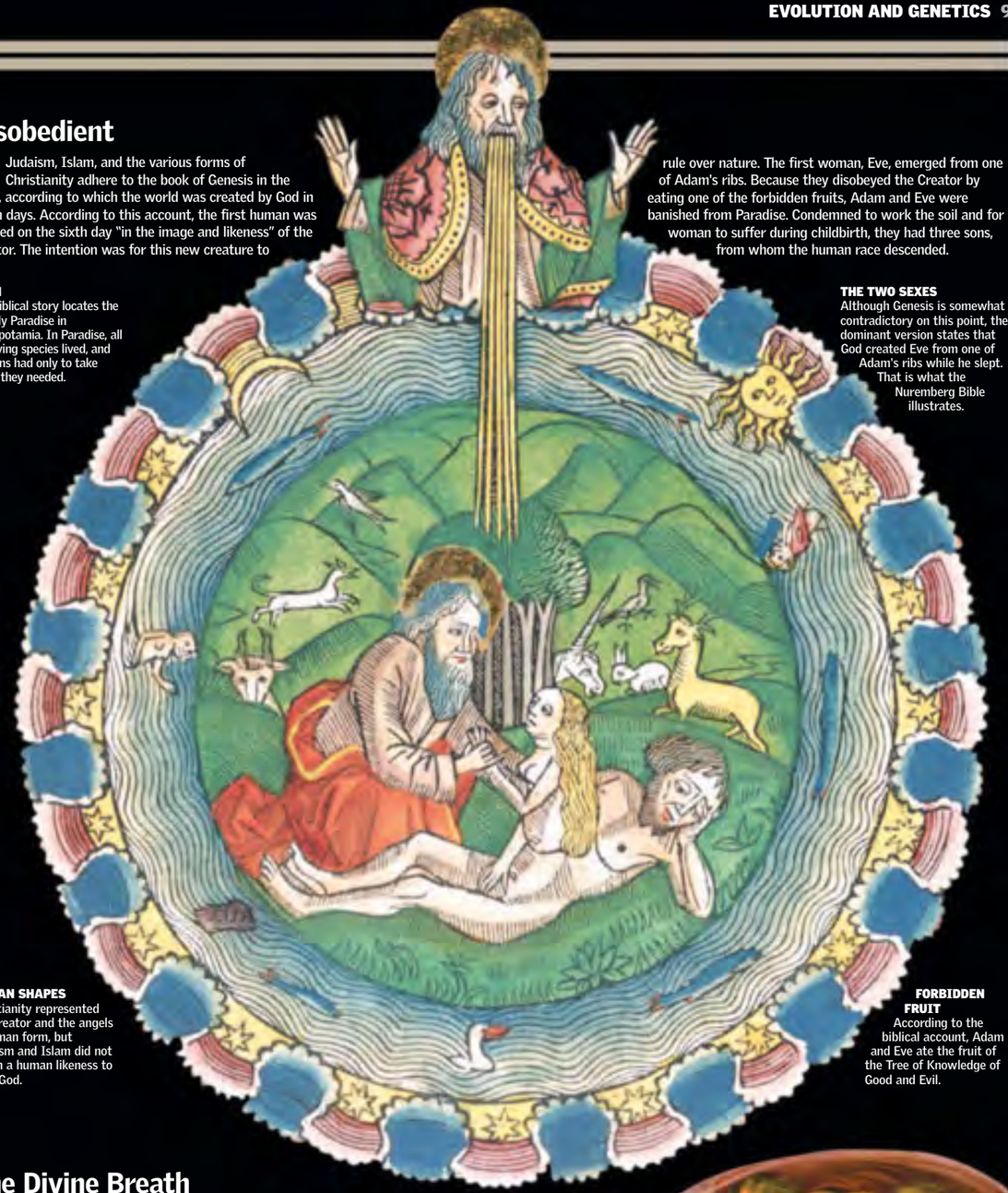
In Africa, the continent that is today believed to be the cradle of the human species, there are several myths that account for the origin of mankind. One of these actually interweaves it with the origin of the monkey. It tells how the creator god Muluku made two holes in the Earth from where the first woman and the first man sprouted and how he taught them the art of agriculture, but they neglected it and the Earth dried up. As punishment, Muluku banished them to the rainforest and gave them monkey tails, and he removed the tails from monkeys and ordered them to be "human."

Disobedient

Judaism, Islam, and the various forms of Christianity adhere to the book of Genesis in the Bible, according to which the world was created by God in seven days. According to this account, the first human was created on the sixth day "in the image and likeness" of the Creator. The intention was for this new creature to rule over nature. The first woman, Eve, emerged from one of Adam's ribs. Because they disobeyed the Creator by eating one of the forbidden fruits, Adam and Eve were banished from Paradise. Condemned to work the soil and for woman to suffer during childbirth, they had three sons, from whom the human race descended.

EDEN
The biblical story locates the earthly Paradise in Mesopotamia. In Paradise, all the living species lived, and humans had only to take what they needed.

THE TWO SEXES
Although Genesis is somewhat contradictory on this point, the dominant version states that God created Eve from one of Adam's ribs while he slept. That is what the Nuremberg Bible illustrates.



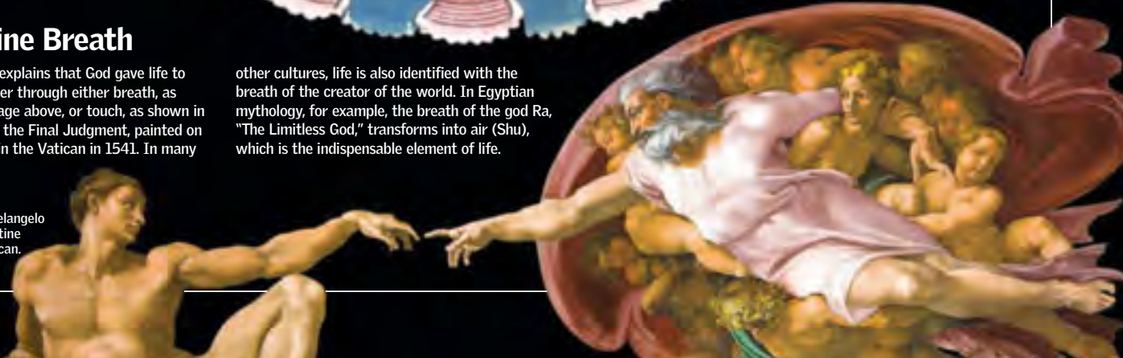
HUMAN SHAPES
Christianity represented the Creator and the angels in human form, but Judaism and Islam did not assign a human likeness to their God.

FORBIDDEN FRUIT
According to the biblical account, Adam and Eve ate the fruit of the Tree of Knowledge of Good and Evil.

The Divine Breath

The story explains that God gave life to inert matter through either breath, as shown in the image above, or touch, as shown in this fragment of the Final Judgment, painted on a chapel ceiling in the Vatican in 1541. In many other cultures, life is also identified with the breath of the creator of the world. In Egyptian mythology, for example, the breath of the god Ra, "The Limitless God," transforms into air (Shu), which is the indispensable element of life.

CREATION
The work of Michelangelo is found in the Sistine Chapel in the Vatican.

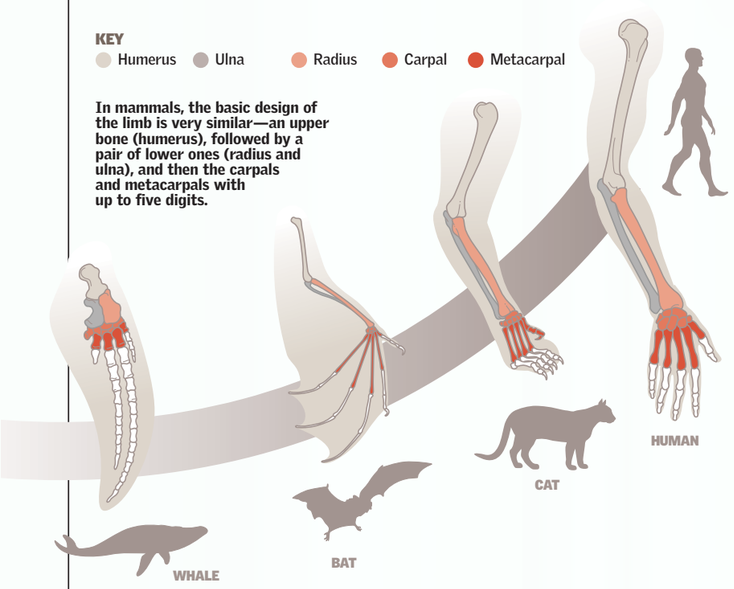


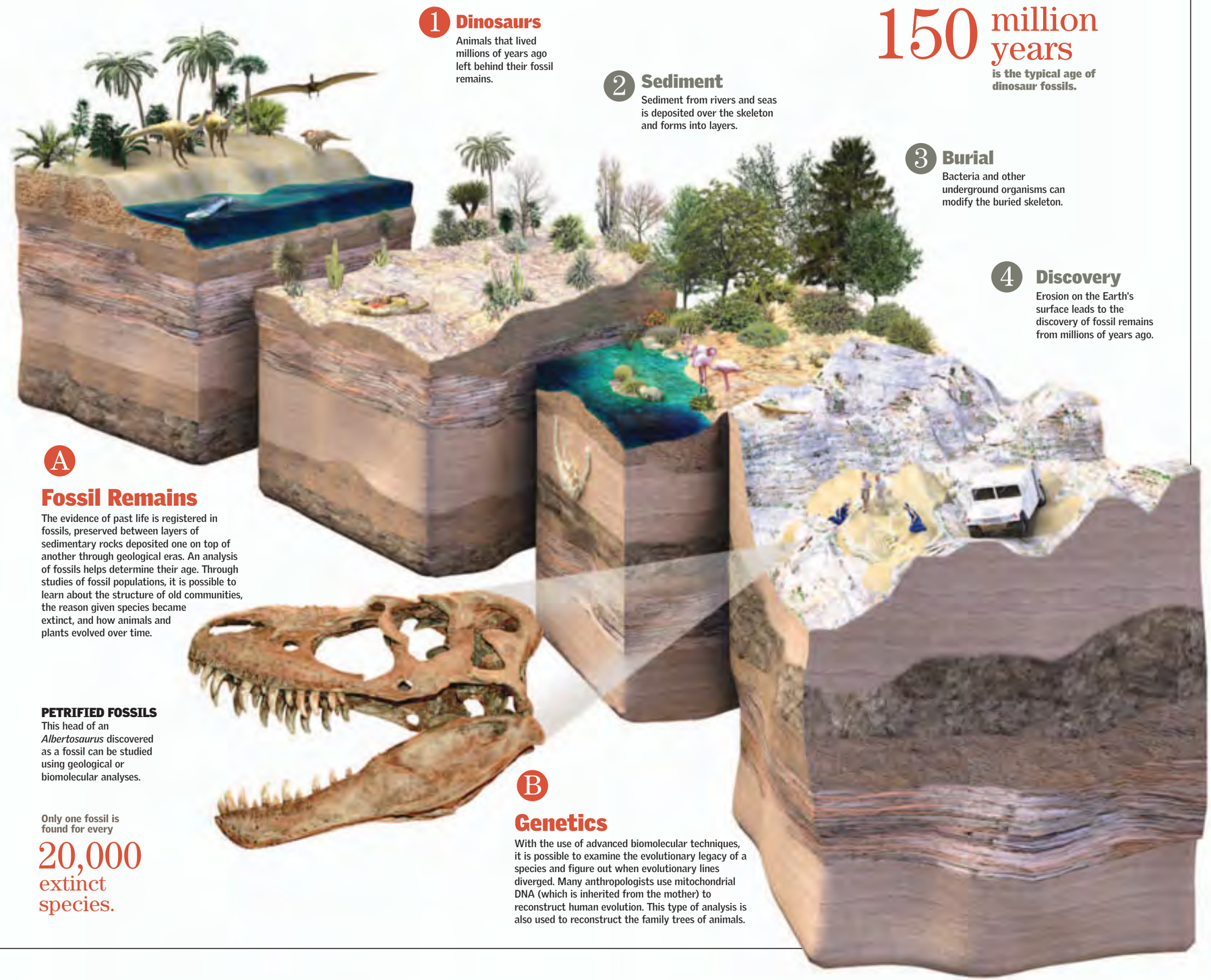
Evolution Is a Matter of Time

Toward the 18th century, scientific progress demanded a different explanation of the myth of the origin of the world and of life. Even before Darwin, the work of naturalists and the discovery of fossils pointed to the fact that time, measured not in years but in millennia, runs its course, allowing each species to become what it is. Genetic mutations occur through the generations, and interaction with the environment determines that the most suitable traits will be transmitted (natural selection) and that a population will evolve in relationship to its ancestors. The idea is not related to "improvement" but rather to change as the origin of diversity, to the ramifications of evolutionary lines tracked through paleontological or genetic studies.

A Common History

Animals that look very different may be built according to the same basic body design. For example, dogs, whales, and human beings are mammals. All have the same skeletal design with a spinal column and two pairs of limbs connected to it. This suggests that they all share a common ancestor. In mammals, the bones of the limbs are the same even if they are morphologically different from one another.





Evolutionary Processes

In addition to natural selection, the famous theory developed by Charles Darwin in the 19th century, there are other evolutionary processes at work at the microevolutionary scale, such as mutations, genetic flow (i.e., migration), and genetic drift. However, for evolutionary processes to take place, there must be genetic variation—i.e., modifications to the proportion of certain genes (alleles) within a given population over time. These genetic differences can be passed on to subsequent generations, thereby perpetuating the evolutionary process.

DREPANA FALCATARIA was found hidden on a tree in Norfolk (U.K.) in 1994.

A Natural Selection

This is one of the basic mechanisms of evolution. It is the process of species survival and adaptation to changes in the environment, and it involves shedding some traits and strengthening others. This revolutionary transformation takes place when individuals with certain traits have a survival or reproduction rate higher than that of other individuals within the same population, thus passing along these genetic traits to their descendants.

GENETIC VARIATION IN THE GIRAFFE

1 COMPETITION
In the 19th century, because of the theories of Darwin and Lamarck, among others, it was believed that the ancestors of giraffes had short necks.

2 MUTATION
On the basis of spontaneous mutations, some individuals developed longer necks, allowing them to survive in the competition for food.

3 ADAPTATION
Their long necks allowed them to survive and pass along this trait to their descendants.

THE GEOMETRIC MOTH AND ITS ENVIRONMENT

The genes of geometric moths, which live on tree bark lichen, have different versions (alleles) for gray and black. At the start of the Industrial Revolution in England, the gray moth was better able to camouflage itself than the black moth and thus better able to avoid predators. All this changed with the emergence of pollution, which blackened tree trunks.

1 MIMESIS
The population of moths with gray alleles grows larger because of its camouflage.

2 POLLUTION
Moths with black alleles find themselves better adapted to their new environment, which is the result of industrial pollution.

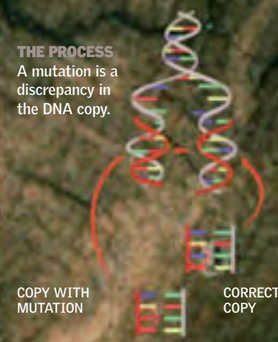
3 SURVIVAL
The population of moths with black alleles grows and surpasses the population with gray alleles.

95%

THE PROPORTION OF BLACK MOTHS FOUND IN URBAN AREAS

B Mutation

involves the modification of the sequences of genetic material found in DNA. When a cell divides, it produces a copy of its DNA; however, this copy is sometimes imperfect. This change can occur spontaneously, such as from an error in DNA replication (meiosis) or through exposure to radiation or chemical substances.



C Genetic Flow

The transfer of genes from one population to another occurs particularly when two populations share alleles (different versions of genes). For example, when a population of brown beetles mixes with a population of green beetles, there might be a higher frequency of brown beetle genes in the green beetles. This also occurs when new alleles combine as a result of mixing, as when Europeans mixed with Native Americans.

D Genetic Drift

A gradual change in the genetic makeup of a population that is not linked to the environment. Unlike natural selection, this is a random process that does not generate adaptations. Genetic drift is present in small populations in which each individual carries within itself a large portion of the genetic pool, especially when a new colony is established (the founding effect), or when a high number of individuals die and the population rebuilds from a smaller genetic pool than before (the bottleneck effect).

To Live or Die

Coevolution is a concept used by scientists to describe the evolutionary process from a group perspective, because no single species has done it in isolation. On the contrary, different levels and types of relationships were established through time between species, exerting changing pressures on their respective evolutionary paths. Natural selection and adaptation, both processes that every species has undergone to the present, depend on these relationships.

COMPETITION
There is also competition within a species, whether for food or for mating partners.

Types of Relationships

If the evolution of each species were an isolated event, neither the relationships nor the adaptations that together generate coevolution would exist. In fact, in the struggle for survival, some species react to the evolutionary changes of other species. In the case of a predator, if its prey were to become faster, the hunt would become more difficult and a demographic imbalance would develop in favor of the prey. Therefore, the speed of each depends on the mutual pressure predator and prey exert on each other. In nature, different types of relationships exist that are not always clear or easily discernible given the complexity they can acquire through the process of coevolution. These range from noninteraction to predation, from cooperation to competition and even parasitism.

A Commensalism

is a relationship between two species of organisms in which one benefits and the other is neither harmed nor helped. There are several types of commensalism: phoresy, when one species attaches itself to another for transportation; inquilinism, when one species is housed inside another; and metabiosis, such as when the hermit crab lives inside the shell of a dead snail.

B Mutualism

is a type of interspecific relationship in which both species derive benefit. It might seem as if this is an agreement between parties, but it is actually the result of a long and complicated process of evolution and adaptation. There are numerous examples of mutualism, although the most famous is the cattle egrets of Africa (*Bubulcus ibis*), which feed on the parasites of large herbivores such as the buffalo and the gnu. To the extent that the egrets obtain their food, the herbivores are rid of parasites.

The Environment

INTERACTS WITH COEVOLUTION, SUCH AS WHEN AN ENVIRONMENTAL CHANGE FAVORS OR HARMS A GIVEN SPECIES.

C Parasitism

is defined as an asymmetric relationship in which only one of the organisms (the parasite) derives benefit. It is an extreme case of predation that entails such fundamental adaptations where the parasite, which enters by various means, might even live inside its host. Such is the case of the African buffalo, which can have a worm called *Elaeophora poeli* lodged in its aorta.

D Competition

takes place when two or more organisms obtain their resources from a limited source. This is a relationship that has one of the strongest impacts on natural selection and the evolutionary process. There are two types of competition. One occurs through interference, which is when an action limits another species' access to a resource—for example, when the roots of a plant prevent another plant from reaching nutrients. The other type of competition is through exploitation, typical among predators such as lions and cheetahs that prey on the same species. In this second type, the principle of competitive exclusion is also at play, since each species tends to eliminate its competition.

Debate

FOR EVOLUTIONARY SCIENTISTS, IT IS NOT CLEAR WHETHER THE DRIVING FORCE OF EVOLUTION IS COOPERATION OR COMPETITION. THE LATTER NOTION HAS BEEN FAVORED BY THE SCIENTIFIC COMMUNITY SINCE THE 19TH CENTURY.

E Predation

is the interspecies relationship in which one species hunts and feeds on another. It is important to understand that each party exerts pressure on and regulates the other. There are specific instances of predation in which the hunter impacts only one type of prey or those in which it feeds on different species. The degree of adaptation depends on this distinction. The lion, the zebra, and the kudu form an example of the latter case.

The Critical Point

One of the big issues posed by the theory of evolution is how a new species arises. This presumes that a population becomes separated from other individuals within its group (when, for example, it lives under conditions different from those of its parents) and ceases to interact with them. Through the generations, the isolated individuals will experience genetic mutations that give rise to phenotypic changes completely different from those experienced by the original population to which they once belonged, and they develop traits so distinct that they become a new species. From an evolutionary perspective, this is how one can understand the constant emergence of new lineages and the growing diversity of living beings.

The origin of new species

Individuals of the same species look alike and breed among themselves, but not with those of other species. In speciation, two or more species arise from a single species (cladogenesis), or several fertile individuals arise from the crossbreeding of two different species (hybridization), although the latter is much less frequent in nature. Cladogenesis can arise out of geographical isolation or simply through a lack of genetic flow between groups of individuals of the same species, even if they are present in the same territory.

THE HONEYCREEPERS

New species can arise from a common ancestor. All the Hawaiian honeycreepers evolved from the same ancestor. They have different colors and bills. The original species is now extinct. The diet of the honeycreeper changed with each new generation.

Akiapola'au
Hemignathus munroi
searches for insects underneath the barks of trees.

Iiwi
Vestiaria coccinea
feeds exclusively on nectar.

Apanane
Himatione sanguinea
feeds on insects and ohia flower nectar.

Maui Parrotbill
Pseudonestor xanthophrys
removes bark in search of beetles.

Bills

Their varying shapes explain the adaptation of each bird to the changes in its diet.

Hawaii Amakihi
Hemignathus virens
has a curved bill and feeds on nectar.

Nihoa Finch
Telespiza ultima
can shatter seeds with its hard beak.

Selection

In spite of their differences, dogs are so similar to each other that they can breed with each other. They are in the same species. But selective breeding is a good example of how differentiation is favored, except that in nature it takes a longer time to do this. Selection can be disruptive, when two populations separate and become differentiated; directional, when the dominant traits of a population change; or stabilizing, when variations diminish and individuals become more similar to each other.

Gray Wolf
Canis lupus
The ancestor of the dog is very intelligent and social. It travels in packs of 8 to 12 members.

Siberian Husky

Canis familiaris

Unlike the German shepherd, which evolved through 10,000 years of human-breeding, the Siberian husky preserves traits closer to those of the gray wolf, which are the ancestors all dogs.

German Shepherd
Canis familiaris
This strong, trainable dog herds cattle and sheep tirelessly and with great intelligence.

Origin of Life

PREHISTORIC ANIMALS
Re-creation of Titanis (a fierce bird) and of the horse Hipparion, two primitive animals that lived during the Cretaceous Period

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THE END OF THE DINOSAURS 32-33
LAND OF MAMMALS 34-35
THE TREE OF LIFE 36-37

An effort of imagination is needed to see just how new complex life-forms are on Earth. For millions of years the development of life was completely static. Suddenly one day this stagnant world exploded unexpectedly with new forms of life, an effect called the Cambrian explosion. The fossil record shows an impressive proliferation of incredibly varied life-forms. The emergence of new species in the oceans took place at the same time as the massive extinction of stromatolites, which had dominated the Proterozoic Eon up to that point. In this chapter you will also discover how new creatures continued to appear that over time populated the face of the Earth. ●

Through Time

Geologic structures and fossils have been used by scientists to reconstruct the history of life on our planet. Scientists believe that the Earth was formed about 4.6 billion years ago and that the first living beings, single-celled organisms, appeared about one billion years later. From that time, the Earth has registered the emergence, evolution, and extinction of numerous species. Thanks to the study of fossils paleontologists can provide an account of plants and animals that have disappeared from the Earth.

HOW IT STARTED

FORMATION OF THE CRUST. The oldest known rocks date to about four billion years ago and the oldest known crystals to about 4.4 billion years ago.

ANAEROBIC AND AQUATIC LIFE. The first atmosphere had no oxygen; the first organisms (bacteria) used anaerobic respiration.

LAVA BECAME ROCK. The first terrestrial surface was a thin layer with scattered volcanoes that spouted very light lava that came from the Earth's interior. As the lava cooled, it hardened and thickened the early crust.

PRESENCE OF OXYGEN. Life on Earth was dependent on the presence of oxygen, which established itself in the atmosphere and over the surface some 2.1 billion years ago. Oxygen makes possible the formation of fundamental compounds, such as water and carbon dioxide, whose molecular model is shown here.

THE FIRST EVIDENCE. Stromatolites, fossils that date back some 3.5 billion years, are one of the first evidences of life on the planet. These formations correspond to single-celled algae that lived underwater. In this image you can see a fossil of ***Collenia***, found in the United States.

A CURIOUS FOSSIL. This fossil in mawsonite found in the Ediacara of Australia is one of the oldest fossils from a metazoan, or multicellular, animal. It is at least 600 million years old. Cnidarians are well-represented among Ediacaran fossils.

4.6 BILLION YEARS AGO. The basic materials that formed the Earth condensed.

1 BILLION YEARS AGO. Several large continental pieces come together, forming the supercontinent Rodinia.

PROTECTED LIFE. The most common animal life-forms of the Cambrian Period already showed well-defined body structures. Many were protected by valves or shells.

CONQUEST OF EARTH. The first land species appeared during the Silurian Period. Plants invaded the first sedimentary areas, and crustaceans came out of the water.

MASSIVE EXTINCTIONS. Great climatic changes and other circumstances produced the first massive extinctions of species, evidenced by great banks of fossils.

METALDETES had a calcareous structure similar to that of sponges. They lived in the Cambrian sea.

CRINOID FOSSIL. The fossils from these archaic marine invertebrates were typical of the Silurian Period and are widely distributed in sedimentary rocks.

THE CAMBRIAN EXPLOSION. Numerous multicellular species suddenly appeared.

THE PRESENCE OF OXYGEN. The first fish, called agnates, had no jaws. This pteraspis, found in shallow waters, belongs to the Silurian Period.

SCALES. The image shows the scales of a Lepidotus, a type of archaic fish. These were covered by a hard and shiny substance similar to enamel. Today most reptiles and fish have scales.

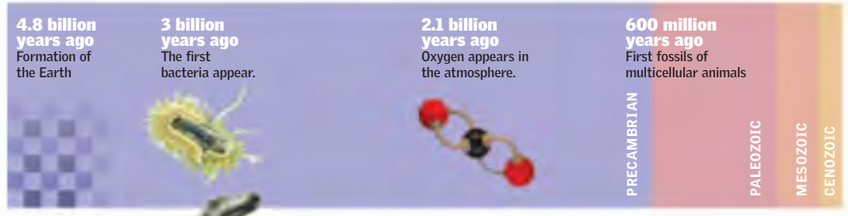
ON FOUR LEGS. This very ancient amphibian, called Acanthostega, lived during the Devonian Period.

270 MILLION YEARS AGO. The mass of solid land is again concentrated in a single continent, called Pangea, that would become the origin of the continents we know today. Repeated glaciations took place, and the central Tethys Sea was formed.

200 MILLION YEARS AGO. Laurasia (North America, Europe, and Asia) and Gondwana (South America, Africa, India, Australia, and Antarctica) separate from each other.

THE TIMELINE

Most of the history of life on the planet has had simple, single-celled organisms, such as bacteria, as the lead actors. Bacteria have survived for more than three billion years. In comparison, the reign of dinosaurs during the Mesozoic Era (about 250 to 65 million years ago) is a recent event. And the presence of humans on Earth is insignificant on this time scale.

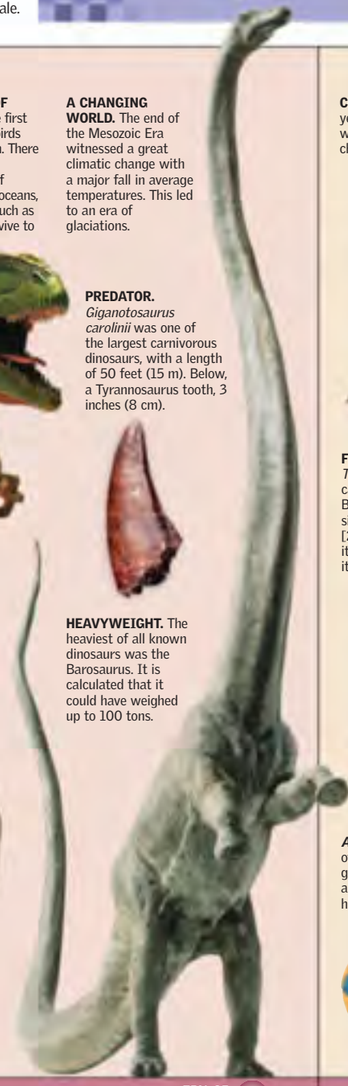


THE ERA OF REPTILES. Large and small, they conquered terrestrial environments, but there were also aquatic species (such as the Icthyosaurus) and others in the air (such as the Pterosaurus).

NEW TYPES OF ANIMALS. The first mammals and birds appear on Earth. There was a great diversification of mollusks in the oceans, where species such as the nautilus survive to this day.

A CHANGING WORLD. The end of the Mesozoic Era witnessed a great climatic change with a major fall in average temperatures. This led to an era of glaciations.

PREDATOR. *Giganotosaurus carolinii* was one of the largest carnivorous dinosaurs, with a length of 50 feet (15 m). Below, a Tyrannosaurus tooth, 3 inches (8 cm).



HEAVYWEIGHT. The heaviest of all known dinosaurs was the Barosaurus. It is calculated that it could have weighed up to 100 tons.

VERTEBRA. This is a fossil vertebra of a *Barosaurus*. The neck was flexible thanks to the light weight of these bones.

200 MILLION YEARS AGO Gondwana separates, forming Africa, Antarctica, Australia, India, and South America.

CHANGING CLIMATE. The first 20 million years of the Cenozoic Era were relatively warm, but at the end of the period climate changed, and the polar caps were formed.

PRAIRIES, THE IDEAL STAGE. The spread of hominin species throughout the planet coincided with the expansion of prairies as the dominant form of vegetation.

FEATHERED. *Titanis* was a carnivorous bird. Because of its size (8.2 feet [2.5 m] tall) and its small wings, it was flightless.

FINALLY ALONE. Without the threat of the large dinosaurs, birds and mammals could develop.

SABER TEETH. *Thylacosmilus* resembled the felines of today, but it was a marsupial. The females had a pouch for the young, like that of kangaroos. Their teeth never stopped growing. Their fossils were found in Argentina; they lived during the Miocene and Pliocene epochs, subdivisions of the Neogene Period.

Australopithecus afarensis. A reconstruction of the head of this hominin is shown here. It was an ancestor of the human genus and lived from 3.7 million to 2.9 million years ago. With a height of 40 inches (1 m), it was smaller than modern humans. According to theory, *Homo habilis* descended from it..

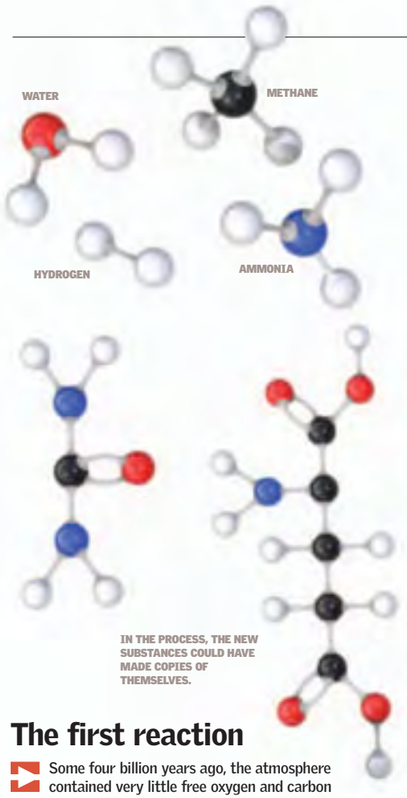
RELATIVES. The first fossils of *Homo neanderthalensis* were found in 1856. They had a common ancestor with *Homo sapiens.*

50 MILLION YEARS AGO The continental masses were in positions similar to those of today. Some of the highest mountain ranges of today, the Alps and the Andes, were being formed. Simultaneously, the subcontinent of India was colliding with Eurasia to form the highest mountain range, the Himalayas.

MASS EXTINCTIONS		60% OF SPECIES		80% OF SPECIES		95% OF SPECIES		75% OF SPECIES				
4.6-2.5 BILLION YEARS AGO	2.5 BILLION-542 MILLION YEARS AGO	542 - 488	488 - 444	444 - 416	416 - 359	359 - 299	299 - 251	251 - 200	200 - 146	146 - 65.5	65.5 - 23	SINCE 23 MILLION YEARS AGO
ARCHEAN EON	PROTEROZOIC EON	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFEROUS	PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	PALEOGENE	NEOGENE
PRECAMBRIAN TIME		PALEOZOIC ERA						MESOZOIC ERA			CENOZOIC ERA	

Chemical Processes

Although it is assumed today that all life-forms are connected to the presence of oxygen, life began on Earth more than three billion years ago in the form of microorganisms. They determined, and still determine today, the biological processes on Earth. Science seeks to explain the origin of life as a series of chemical reactions that occurred by chance over millions of years and that gave rise to the various organisms of today. Another possibility is that life on Earth originated in the form of microbes that reached the Earth from space, lodged, for instance, within a meteorite that fell to the Earth's surface.



IN THE PROCESS, THE NEW SUBSTANCES COULD HAVE MADE COPIES OF THEMSELVES.

The first reaction

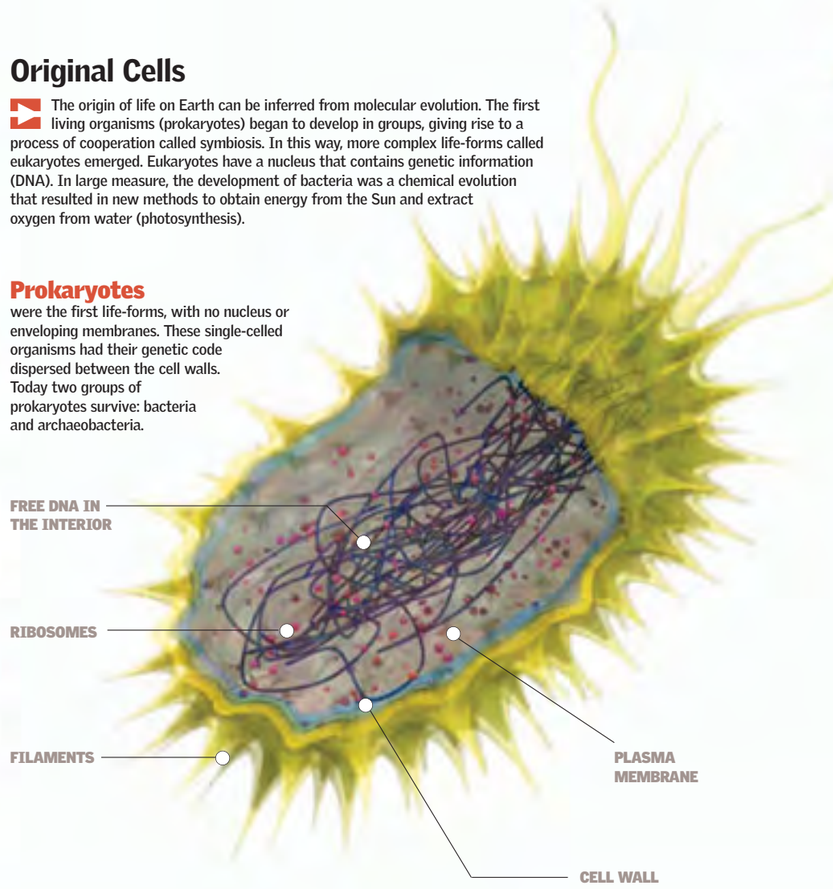
Some four billion years ago, the atmosphere contained very little free oxygen and carbon dioxide. However, it was rich in simple chemical substances, such as water, hydrogen, ammonia, and methane. Ultraviolet radiation and discharges of lightning could have unleashed chemical reactions that formed complex organic compounds (carbohydrates, amino acids, nucleotides), creating the building blocks of life. In 1953, Americans Harold Urey and Stanley Miller tested this theory in the laboratory.

Original Cells

The origin of life on Earth can be inferred from molecular evolution. The first living organisms (prokaryotes) began to develop in groups, giving rise to a process of cooperation called symbiosis. In this way, more complex life-forms called eukaryotes emerged. Eukaryotes have a nucleus that contains genetic information (DNA). In large measure, the development of bacteria was a chemical evolution that resulted in new methods to obtain energy from the Sun and extract oxygen from water (photosynthesis).

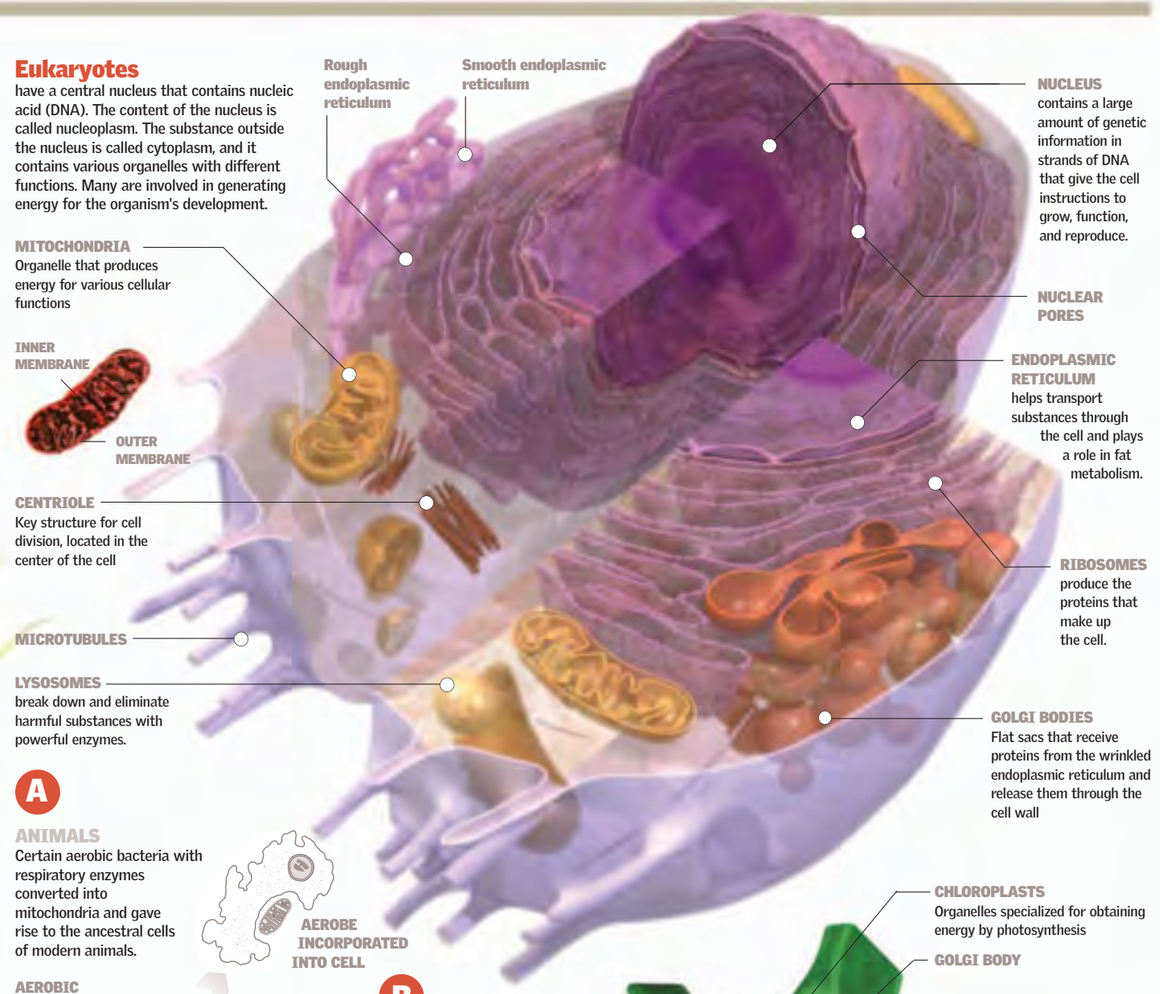
Prokaryotes

were the first life-forms, with no nucleus or enveloping membranes. These single-celled organisms had their genetic code dispersed between the cell walls. Today two groups of prokaryotes survive: bacteria and archaeobacteria.



Eukaryotes

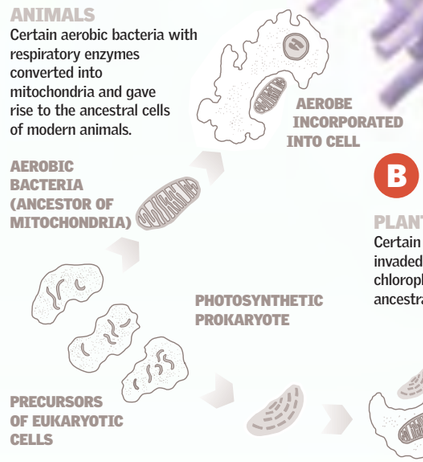
have a central nucleus that contains nucleic acid (DNA). The content of the nucleus is called nucleoplasm. The substance outside the nucleus is called cytoplasm, and it contains various organelles with different functions. Many are involved in generating energy for the organism's development.



A

ANIMALS

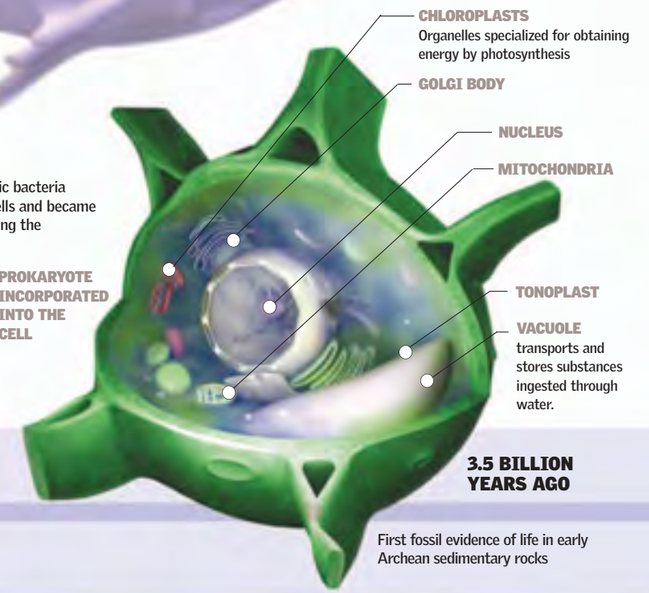
Certain aerobic bacteria with respiratory enzymes converted into mitochondria and gave rise to the ancestral cells of modern animals.



B

PLANTS

Certain photosynthetic bacteria invaded eukaryotic cells and became chloroplasts, originating the ancestral plant cell.



ARCHEAN

4.6 BILLION YEARS AGO

The Earth's atmosphere sets it aside from the other planets.

4.2 BILLION YEARS AGO

Volcanic eruptions and igneous rock dominate the Earth's landscape.

4 BILLION YEARS AGO

The Earth's surface cools and accumulates liquid water.

3.8 BILLION YEARS AGO

Prebiotic evolution in which inert matter is transformed into organic matter

3.5 BILLION YEARS AGO

First fossil evidence of life in early Archean sedimentary rocks

Fossil Relics

The term proterozoic comes from the Greek *proteros* ("first") and *zoic* ("life") and is the name given to an interval of geologic time of about two billion years at the end of what is known as Precambrian time. The oldest fossils of complex organisms yet found, in the Ediacara fossil bed (Australia), date from the end of the Proterozoic, in the Neoproterozoic Era. It is the first evidence of multicellular organisms with differentiated tissues. It is believed that the specimens of Ediacara life were not animals but prokaryotes that were formed of various cells and did have internal cavities. Toward the end of the Proterozoic, there was a global disturbance in the carbon cycle that caused the disappearance of most complex organisms and opened the way for the great explosion of life in the Cambrian Period.

CHARNIA
is one of the largest fossils of the Ediacaran Period. Its flat, leaf-shaped body was supported by a disklike structure.

Primitive Species

It has been established that the animals of the Ediacara were the first invertebrates on the Earth. They appeared approximately 650 million years ago and were made up of various cells. Some had a soft flat body while others were in the form of a disk or a long strip. A relevant fact about the life of this period is that they no longer had only one cell that was in charge of feeding, breathing, and reproducing; instead, the diverse cells specialized in distinct functions.

40 inches
(100 cm)
MAXIMUM LENGTH

STROMATOLITES
are the most ancient evidence of life known on Earth, and even today they have maintained their evolutionary line. They are laminated organic-sedimentary structures, principally cyanobacteria and calcium carbonate, stuck to the substrate product of metabolic activity. They grew in mass, which led to the formation of reefs.

CALCIUM CARBONATE

CYANOBACTERIA

MAWSONITE
This species of cnidarian shifted slowly through the waters, aided by the currents. It contracted its long, thin umbrella, extending its tentacles and shooting its microscopic harpoons to capture its prey. For this, it also used a kind of poison.

CYCLOMEDUSA
Ancient circular fossil with a bump in the middle and up to five concentric ridges. Some radial segments extend along the length of the outer disks.

3.5-4 inches
(9-10 cm)
IN DIAMETER

KIMBERELLA
An advanced metazoan from the Ediacara fauna, it is the first known organism with a body cavity. It is believed to have been similar to a mollusk and was found in Russia in 1993.

8 inches
(20 cm)
IN LENGTH

1 inch
(2.5 cm)
IN LENGTH

DICKINSONIA
Usually considered an annelid worm because of its similar appearance to an extinct genus (*Spinther*). It also may be a version of the soft body of the banana coral fungus.

TRIBRACHIDIUM
It is believed that this species, developed in the form of a disk with three symmetric parts, is a distant relative to corals and to anemones such as starfish.

40 inches
(100 cm)
IN LENGTH

2 inches
(5 cm)
IN DIAMETER

3 BILLION YEARS AGO

Accumulation of iron oxide on the seafloor

2.3 BILLION YEARS AGO

Extensive glaciation takes place.

600 MILLION YEARS AGO

Multicellular marine organisms called Ediacara fauna develop.

The Cambrian Explosion

Unlike the previous development of microbial life, the great explosion of life that emerged in the Cambrian some 500 million years ago gave rise to the evolution of a diversity of multicellular organisms (including mollusks, trilobites, brachiopods, echinoderms, sponges, corals, chordata) protected by exoskeletons or shells. It is believed that this group of organisms represents the characteristic fauna of the Cambrian. The Burgess Shale fossil bed in British Columbia (Canada) holds a large number of fossils of soft-bodied animals of the period and is one of the most important fossil formations in the world.

Burgess Shale

Located in Yoho National Park in the Canadian province of British Columbia, Burgess Shale is a celebrated fossil bed found in 1909 by the American paleontologist Charles Walcott. Burgess Shale offers a unique look at the explosion of Cambrian life. It contains thousands of very well—preserved fossilized invertebrates, including arthropods, worms, and primitive chordata, some with their soft parts intact.

Provided with a strong exoskeleton, the *Anomalocaris* was a true terror in the Cambrian seas.

0.4 inch (10 mm)

ANOMALOCARIS
The largest plundering arthropod known of that time, it had a circular mouth, appendages that allowed it to strongly grasp its prey, and fins along the length of both sides that were used for swimming. In comparison to other organisms, it was a true giant of Burgess Shale.

Comparison to human scale

24 inches (60 cm)
THE LENGTH REACHED BY THIS SPECIES

PIKAIA
One of the first chordates, similar to an eel, with a tail in the shape of a flipper. It is the oldest known ancestor to vertebrates.

4 inches (10 cm) long
INCLUDING THE TAIL

MARELLA
Small swimming arthropod that was probably an easy prey for predators in Burgess Shale.

4 inches (10 cm) in length
TO THE EXTREMITIES

SPONGES
They grew primarily on the seabed in Burgess Shale and frequently developed alongside algae of diverse species, sizes, and shapes.

HALLUCIGENIA
Had a defense system based on long spines that simultaneously served as feet for its movement.

1.2 inches (3 cm) maximum length
OF THIS ARTHROPOD

PRIAPULIDS
Benthic worms that live buried in sand and in the mud of shallow water as well as in deep water. There are about 15 species.

0.8 inch (2 cm) IN LENGTH

CAMBRIAN
(542 TO 488 MILLION YEARS AGO)

CAMBRIAN BEGINS
The increased presence of oxygen permitted the formation of shells.

THE EVOLUTIONARY EXPLOSION
The Cambrian originated a great variety of body designs.

CORAL REEFS
are formed by the calcareous skeletons of innumerable soft bodied animals.

Conquest of the Earth

The Paleozoic Era (ancient life) was characterized by successive collisions of continental masses, and the occupation of their interior lakes made possible the appearance of primitive terrestrial plants, the first fish adapted to freshwater, and amphibians, highlighting a key evolutionary event: the conquest of the terrestrial surface some 360 million years ago. For this process, diverse mechanisms of adaptation were necessary, from new designs of vascular plants and changes in the bone and muscular structures to new systems of reproduction. The appearance of reptiles and their novel amniotic egg meant the definitive colonization of the land by the vertebrates, just as the pollen made plants completely independent of water.

0.2 inch
(6 mm)
MEGANEURA

From fins to limbs

The amphibian evolution facilitated the exploration of new sources of foods, such as insects and plants, and an adaptation of the respiratory system for the use of oxygen in the air. For this purpose, the aquatic vertebrates had to modify their skeleton (a greater pelvic and pectoral waist) and develop musculature. At the same time, the fins transformed into legs to permit movement on land.

ACANTHOSTEGA

Comparison to human scale

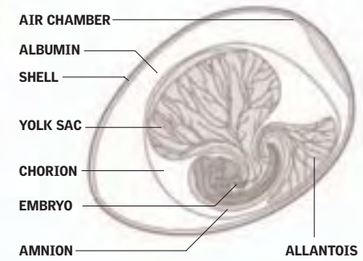
DORSAL SPINE
Its system of joints, called zygapophyses, between the vertebrae helps to maintain the rigidity of the dorsal spine.

35-47 inches
(90-120 cm)
MAXIMUM LENGTH

PREDATOR
The development of a large mouth allowed it to hunt other vertebrates.

FIRST FISH AND PLANTS

The success of the vertebrates in the colonization of land came in part from the evolution of the amniotic egg covered in a leathery membrane. In the evolution of plants, pollen made them independent of water.



0.2 inch
(6 mm)

New breed of fish

After the decline of the trilobites and the appearance of corals, crinoids, bryozoa, and pelecypods came the fish with external bony shields and no jaws, which are the first—known vertebrates. During the Silurian Period, the cephalopods and jawed fish abounded in a globally warm climate. The adaptation of the fish as much to freshwater as saltwater coincided with the predominance of boned fish, from which amphibians developed.

30 feet
(9 m)
THE LENGTH REACHED BY DUNKLEOSTEUS

Skull and jaw of a barracuda

JAW

The key in the evolution of the vertebrates, allowing a predatory way of life, since they could now firmly grasp prey, manipulate it, and cut it

Dorsal fin

The Devonian Period is known as the age of fish.

Thin lobular fin

Head and chest plates connected

Bony teeth with sharpened vertexes

DUNKLEOSTEUS
Comparison to human scale

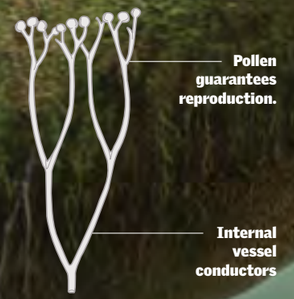
FIN

To move itself through the water, the acanthostega moved its fin, sweeping from side to side. It maintained this characteristic in its move to land.

BONE STRUCTURE
Only three bones (humerus, cubitus, and radius) formed the bone support of the legs. Unlike fish, it had a type of mobile wrist and eight fingers that moved all at once like a paddle.

DEVELOPMENT OF VESSELS IN PLANTS

The need to transport water from the root to the stem and to transport photosynthetic products in the opposite direction in plants induced the development of a system of internal vessels. Reproduction based on pollen achieved the definite conquest of the terrestrial environment.



Pollen guarantees reproduction.

Internal vessel conductors

ORDOVICIAN
488 TO 444 MILLION YEARS AGO

The first land organisms appear—lichens and bryophytes.

SILURIAN
444 TO 416 MILLION YEARS AGO

Great coral reefs and some types of small plants

DEVONIAN
416 TO 359 MILLION YEARS AGO

Vascular plants and arthropods form diverse terrestrial ecosystems.

CARBONIFEROUS
359 TO 299 MILLION YEARS AGO

Land tetrapods and winged insects appear.

PERMIAN
299 TO 251 MILLION YEARS AGO

Large variety of insects and vertebrates on land

The Reign of the Dinosaurs

From abundant fossil evidence, scientists have determined that dinosaurs were the dominant form of terrestrial animal life during the Mesozoic Era. There was a continual change of dinosaur species. Some of them lived during the three periods of the Mesozoic Era, others throughout two, and some in only one. Unlike the rest of the reptiles, the legs of dinosaurs were placed not toward the side but under the body, as they appear in mammals. This arrangement, together with its bone structure (a femur articulated to a hollow pelvis) significantly aided its locomotion. In their evolution, the dinosaurs also developed such defensive features as horns, claws, hornlike beaks, and armor. It was long believed that dinosaurs were cold-blooded; nevertheless, the dominant hypothesis today is that they were warm-blooded. They mysteriously became extinct toward the end of the Cretaceous Period. ●

COMPARATIVE SIZE

The *Plateosaurus* walked on four legs but could reach elevated foliage with support from its tail.

Up to 33 feet (10 m) *PLATEOSAURUS* (FLAT REPTILE)

Triassic Period

Following the massive extinction and biological crisis at the end of the Permian Period, only a relatively few species of plants and animals were able to survive. In the Triassic, the regeneration of life slowly began. Mollusks dominated in marine environments, and reptiles dominated on land. As for plants, families of ferns, conifers, and bennettitales appeared during the middle and late Triassic.

MAMMALS

At the end of the Triassic, there are traces of mammals, which evolved from cynodont reptiles. Among the mammalian characteristics that made their appearance were elongated and differentiated teeth and a secondary palate.

FERN PALM CONIFER GINGKO

Jurassic Period

The increase in sea levels inundated interior continental regions, generating warmer and more humid environments that favored the development of life. The reptiles adapted to diverse environments, and the dinosaurs developed greatly. During this period, there are examples of herbivore dinosaurs existing together with carnivorous dinosaurs. Freshwater environments were favorable for the evolution of invertebrates, amphibians, and reptiles such as turtles and crocodiles. The first birds emerged.

BIPEDALISM

The *Allosaurus*, a giant therapod carnivore, was one of the first species to move about on two legs.

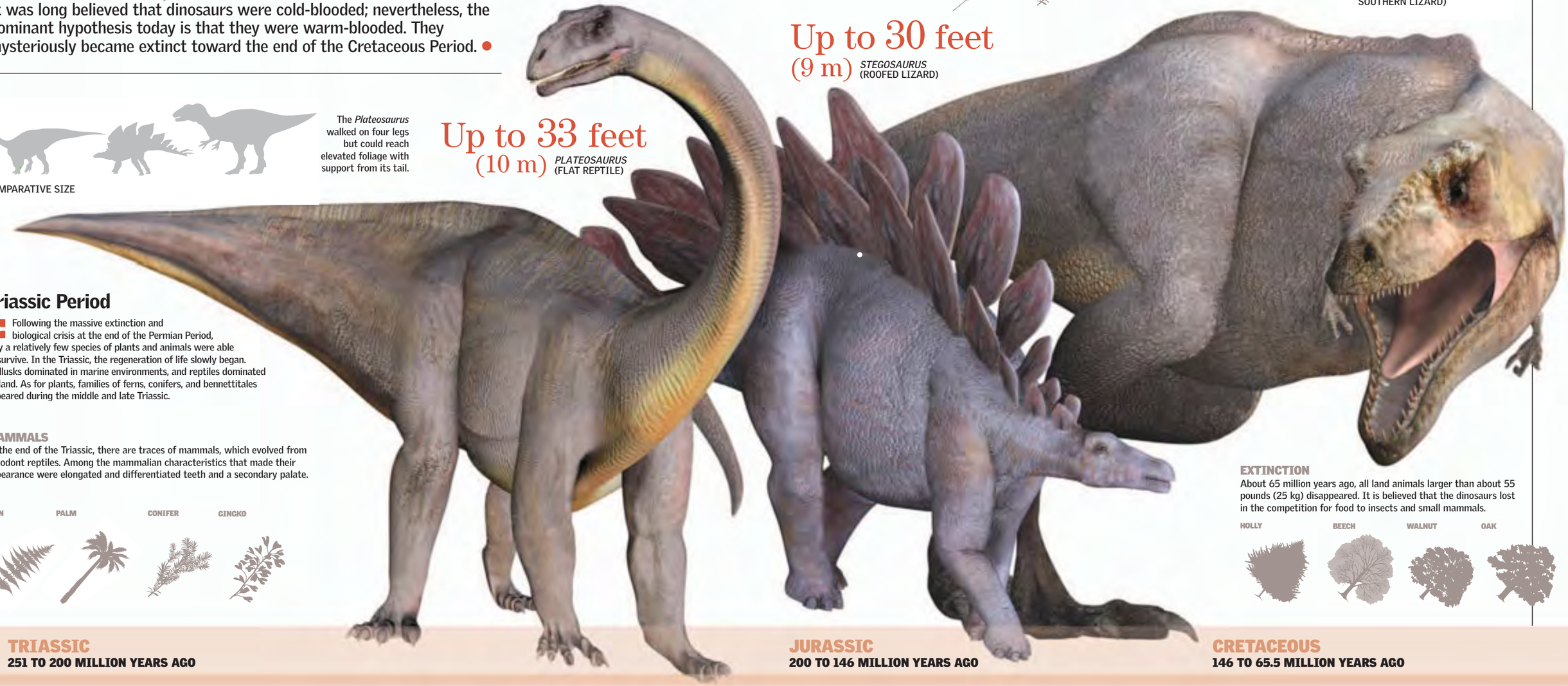
HORSETAIL CONIFER

Up to 30 feet (9 m) *STEGOSAURUS* (ROOFED LIZARD)

Cretaceous Period

In this period, carnivorous dinosaurs appeared with claws curved in the shape of a sickle, specially designed to gut its prey. A prime example is the claw of *Baryonyx*. It measures 12 inches (30 cm), a disproportionate length for an animal 30 feet (9 m) in length. During the Cretaceous Period, the evolution of insects and birds continued, and flora that made use of pollination developed. Nevertheless, this period was marked both by a revolution in the seas (the appearance of new groups of predators, such as teleost fish and sharks) and by a revolution on land (the extinction of the dinosaurs about 65 million years ago).

Up to 50 feet (15 m) *GIGANOTOSAURUS* (GREAT SOUTHERN LIZARD)



EXTINCTION

About 65 million years ago, all land animals larger than about 55 pounds (25 kg) disappeared. It is believed that the dinosaurs lost in the competition for food to insects and small mammals.

HOLLY BEECH WALNUT OAK

TRIASSIC
251 TO 200 MILLION YEARS AGO

The equatorial supercontinent of Pangea forms.

JURASSIC
200 TO 146 MILLION YEARS AGO

Fragmentation of Pangea and increase in sea level

CRETACEOUS
146 TO 65.5 MILLION YEARS AGO

Present-day oceans and continental masses are defined.

The End of the Dinosaurs

Dinosaurs reigned over the Earth until about 65 million years ago. All of a sudden they died out because of a drastic change in the conditions that made their life possible. The most reasonable hypothesis for this change attributes it to the collision of a large asteroid or comet with the Earth. The resulting fire devastated all of what today are the North and South American continents. The impact raised huge dust clouds that remained suspended in the air for months, darkening the planet. At the same time, sulfur, chlorine, and nitrogen was mixed into dense clouds, causing killing acid rains.

More Theories About the "K-T Boundary"

The period between the Cretaceous and Paleogene periods, known as the "K-T boundary," marks the end of the era of the dinosaurs. Although the impact theory is widely accepted, other theories suggest that there was a great change in climate that caused dinosaurs to become extinct very slowly as the shallow seas withdrew from solid land. According to the defenders of these theories, the dinosaurs were being reduced in variety and number throughout a period that lasted millions of years. The large meteorite of Chicxulub, according to this hypothesis, would have fallen some 300 thousand years before the end of the Cretaceous Period. It has also been hypothesized that mammals proliferated before the extinction and fed on reptile eggs, or that the plants eaten by the large sauropods succumbed to diseases.

6 miles (10 km)
WAS THE DIAMETER OF THE METEORITE THAT FELL IN CHICXULUB.

Chicxulub, Mexico

A Profound Evidence

In the Mexican town of Chicxulub, on the Yucatán Peninsula, there is a depression 62 miles (100 km) in diameter that is attributed to the impact of a meteorite about 65 million years ago. The layers of rock that make up the soil support this theory and make it possible to see what occurred before and after the impact.

B VOLCANIC ERUPTIONS

Another theory relates the massive extinction with the appearance of prolonged volcanic eruptions on Earth that emitted asphyxiating gases and darkened the skies with dust. Thousands of cubic miles of volcanic rock found on a plateau in Deccan, India, support this theory.

C SPACE CATACLYSM

Every 67 million years, the Solar System crosses through the plane of the Milky Way. At those times some stars in the Milky Way can cause comets to escape from the Oort cloud and enter the inner Solar System. It is possible that one of these bodies could have impacted the Earth.

50%
OF LIVING SPECIES
became extinct at the same time.

POST-EXTINCTION
sediments accumulated in the Cenozoic Era.

DUST AND ASH
From the impact of the fireball

EJECTED ROCK
Material from the crater that has settled

PRE-EXTINCTION
Sediments with fossils of dinosaurs

IN THE ROCKS
In the region of the Yucatán, rocks made of meteorite fragments are commonly found compressed among the (darker) mineral sediments.

50 million
ATOMIC BOMBS
is the equivalent, according to calculations, of the energy unleashed by the impact in Chicxulub.

K-T BOUNDARY
65 MILLION YEARS AGO

Sudden climatologic change, 65 million years ago

PALEOGENE
65.5 TO 23 MILLION YEARS AGO

Beginning of the Cenozoic Era which extends to the present.

Land of Mammals

After the extinction of the large dinosaurs at the end of the Mesozoic Era, mammals found the opportunity to evolve until becoming sovereigns of the Earth. The Cenozoic Era, which began 65.5 million years ago, also saw the appearance and evolution of plants with flowers, and large mountain chains of today (the Himalayas, the Alps, and the Andes) formed. Within the zoological class of mammals, primates appeared, as did the *Homo* genus, the immediate ancestors of humans, toward the end of the era. ●

The Class that Defines an Era

Some 220 million years ago, the mammaliaformes appeared, which today are all extinct. More similar to reptiles, they already had larger skulls and were beginning to raise their stomachs from the ground with the strength of their limbs. And 100 million years ago, the two predominant surviving suborders appeared—the marsupials (which remain only in Oceania, with the exception of the American opossum) and the placentals (which colonized the entire Cenozoic world).

200 million years
MAMMALS HAVE BEEN ON LAND

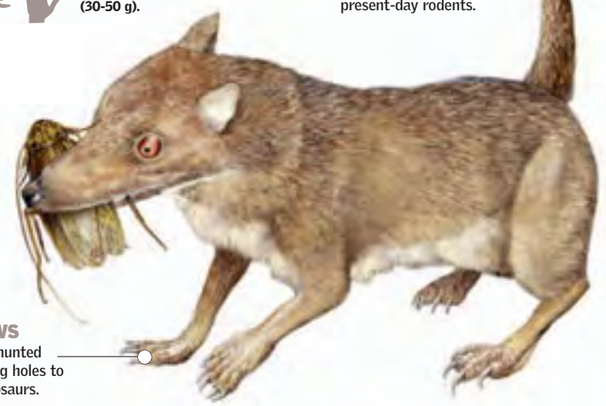
MORGANUCODON

Extinct insectivorous rodent of the Jurassic (200 million years ago)

COMPARATIVE SIZE

Its total length was 6 inches (15 cm), and it weighed from 1 to 2 ounces (30-50 g).

SHORT TAIL
The appendage of the vertebral column, it ended in a point. This differentiates it from present-day rodents.



LONG CLAWS
With these it hunted insects and dug holes to hide from dinosaurs.

CONTINENTS OF THE PAST

PRESENT-DAY CONTINENTS

Ancestors of Humans

Primates are mammals that are characterized by binocular vision, the large relative size of their brains, and the prehensile limbs that allowed them, among others things, to take to the branches of trees and make use of objects as rudimentary tools. The first primates (called *Purgatorius*) appeared in North America in the Paleocene Epoch. The oldest fossils of monkeys (anthropoids) date from some 53 million years ago, but the origin is still uncertain.

Theropithecus oswaldi

COMPARATIVE SIZE

Size similar to a human, 3 to 6 feet (1-2 m)

PRIMATES APPEAR IN THE CENOZOIC ERA.

PREHENSILE THUMB
One finger opposite the rest, predecessor to the thumb of humans, allowed this European monkey of the Pliocene to manipulate objects (5 million years ago).

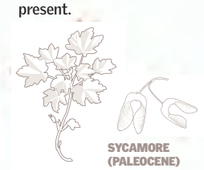
TAIL
They used it for climbing equilibrium. In American monkeys, the tail was prehensile: it allowed them to hang from branches.

60 million years ago
SINCE THE APPEARANCE OF PRIMATES ON EARTH

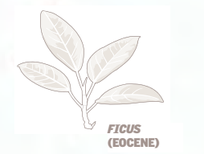
LONG FINGERS
are what first permitted the anthropoids to hold onto the branches and move through the trees.

New Plants

The vegetation that appeared after the extinction of the dinosaurs was very different from previous forms. In the Paleocene and Pleistocene, a tropical climate predominated, but afterward the species of temperate climates have excelled to the present.



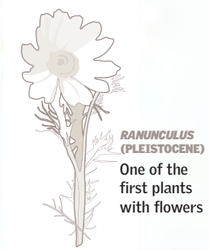
SYCAMORE (PALEOCENE)



FICUS (EOCENE)

GRASSES (PLIOCENE)

SPRUCE (PLEISTOCENE)
Establishment of the conifers



RANUNCULUS (PLEISTOCENE)
One of the first plants with flowers

PALEOGENE
65.5 TO 23 MILLION YEARS AGO

Mammals are represented by marsupials, prosimians, and ungulates.

NEOGENE
FROM 23 MILLION YEARS AGO

Hominoids disperse from Africa to all over the world.

PLEISTOCENE
FROM 1.8 MILLION TO 12,000 YEARS AGO

Development of the first *Homo sapiens.*

HOLOCENE
FROM 12,000 YEARS AGO TO THE PRESENT

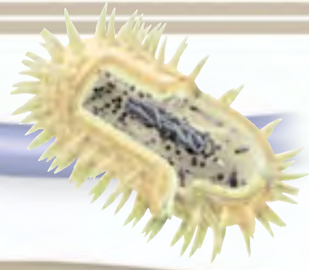
First fossil records of *Homo sapiens sapiens*

The Tree of Life

Here is a visual representation to explain how all living beings are related. Unlike genealogical trees, in which information supplied by families is used, phylogenetic trees use information from fossils as well as that generated through the structural and molecular studies of organisms. The construction of phylogenetic trees takes into account the theory of evolution, which indicates that organisms are descendants of a common ancestor.

Bacteria

Unicellular organisms that live on surfaces in colonies. Generally they have one cellular wall composed of peptidoglycans, and many bacteria have cilia. It is believed that they existed as long as three billion years ago.



COCCALS The pneumococcals are an example.

BACILLUS *Escherichia coli* has this form.

SPIRILLUM In the form of a helicoid or spiral

VIBRIO Found in saltwater

Eukaryota

This group consists of species that have a true nucleus in their cellular structure. It includes unicellular and multicellular organisms, which are formed by specialized cells that do not survive independently.

Protista

A paraphyletic group, it includes the species that cannot be classified in any other group. There are, therefore, many differences among protista species, such as algae and the amoeba.

10,000,000

SPECIES OF ANIMALS ARE CALCULATED TO INHABIT THE EARTH IN THEIR DISTINCT ENVIRONMENTS.

Fungi

Cellular heterotrophic organisms with cell walls thickened with chitin. They carry out digestion externally and secrete enzymes to reabsorb the resulting molecules.

BASIDIOMYCETES include the typical capped mushrooms.

ZYGOMYCETES reproduce through zygospores.

ASCOMYCETES Most species are grouped here.

CHYTRIDIOMYCETES can have mobile cells.

DEUTEROMYCETES Asexual reproduction

ABOUT

5,000

SPECIES OF MAMMALS ARE INCLUDED IN THREE GROUPS.

Animals

Multicellular and heterotrophic. Two of their principal characteristics are their mobility and their internal organ systems. Animals reproduce sexually, and their metabolism is aerobic.

CNIDARIANS include species such as the jellyfish and corals.

BILATERAL Symmetrical bilateral organisms

Archaea

These organisms are unicellular and microscopic. The majority are anaerobic and live in extreme environments. About one half of them give off methane in their metabolic process. There are more than 200 known species.

EURYARCHAEOTA *Halobacteria salinarum*

KORARCHAEOTA The most primitive of the archaea

CRENARCHAEOTA live in environments with high temperatures.

Plants

Multicellular autotrophic organisms; they have cells with a nucleus and thick cellular walls that are grouped in specialized tissues. They carry out photosynthesis by means of chloroplasts.

NOT VASCULAR No internal vessel system

VASCULAR Internal vessel system

SEEDLESS They are small plants with simple tissues.

WITH SEED Some have exposed seed and some have flower and fruit.

ANGIOSPERM With flower and fruit. More than 250,000 species form this group.

GYMNOSPERM With naked seeds; cycadophytes were examples.

MOLLUSKS include the octopus, snails, and oysters.

VERTEBRATES have a vertebral column, a skull that protects the brain, and a skeleton.

CARTILAGINOUS FISH include the rays and sharks.

TETRAPODS Animals with four limbs

AMPHIBIANS When young they are water dwellers; later they live on land.

ARTHROPODS have an external skeleton (exoskeleton). Their limbs are jointed appendages.

INSECTS The greatest evolutionary success

MYRIAPODS Millipedes and centipedes

ARACHNIDS Spiders, scorpions, and acarids

BONY FISH have spines and a jaw.

CRUSTACEANS Crabs and ocean lobsters

AMNIOTES Species that are born from an embryo inside an amniotic egg

MAMMALS The offspring are fed with mother's milk.

PLACENTAL The offspring are born completely developed.

MARSUPIALS The embryo finishes its development outside of the mother.

MONOTREMES The only oviparous mammals. They are the most primitive.

BIRDS AND REPTILES Oviparous species. Reptiles are ectothermic (cold-blooded).

TURTLES The oldest reptiles

LIZARDS Also includes crocodiles

SNAKES Scaly and with long bodies

Cladistics

This classification technique is based on the evolutionary relationship of species coming from similar derived characteristics and supposes a common ancestor for all living species. The results are used to form a diagram in which these characteristics are shown as branching points that have evolved; at the same time, the diagram places the species into clades, or groups. Although the diagram is based on evolution, its expression is in present-day characteristics and the possible order in which they developed. Cladistics is an important analytical system, and it is the basis for present-day biological study. It arises from a complex variety of facts: DNA sequences, morphology, and biochemical knowledge. The cladogram, commonly called the tree of life, was introduced in the 1950s by the German entomologist Willi Hennig.

Relationships

The scientific evidence supports the theory that life on Earth has evolved and that all species share common ancestors. However, there are no conclusive facts about the origin of life. It is known that the first life-forms must have been prokaryotes, or unicellular beings, whose genetic information is found anywhere inside their cell walls. From this point of view, the archaea are prokaryotes, as are bacteria. For this reason, they were once considered to be in the same kingdom of living things, but certain characteristics of genetic transmission places them closer to the eukaryotes.

Amniotes

The evolution of this feature allowed the tetrapods to conquer land and to adapt to its distinct environments. In amniote species the embryo is protected in a sealed structure called the amniotic egg. Among mammals, only monotremes continue to be oviparous; however, in the placental subclass, to which humans belong, the placenta is a modified egg. Its membranes have transformed, but the embryo is still surrounded by an amnion filled with amniotic fluid.

Humans

Humans belong to the class Mammalia and specifically share the subclass of the placentals, or eutherians, which means that the embryo develops completely inside the mother and gets its nutrients from the placenta. After birth, it depends on the mother, who provides the maternal milk in the first phase of development. Humans form part of the order Primates, one of the 29 orders in which mammals are divided. Within this order, characteristics are shared with monkeys and apes. The closest relatives to human beings are the great apes.

Human Evolution

NEANDERTHAL
Our close cousin was strong, an able hunter, and an excellent artisan. Nobody can explain why the Neanderthals disappeared.

HUMAN EVOLUTION 40-41
FIRST HUMANS 42-43
USE OF TOOLS 44-45
ABLE HUNTERS 46-47
DIRECT ANCESTORS 48-49
CULTURE, THE GREAT LEAP 50-51
URBAN REVOLUTION 52-53

Homo sapiens, the name that scientifically designates our species, is the result of a long evolutionary process that began in Africa during the Pliocene Epoch. Very few fossils have been found, and there are no clear clues about what caused the amazing development of the culture. Some believe that a change in the brain or vocal apparatus permitted the emergence of a complex language. Other theories hypothesize that a change in the architecture of the human mind allowed *Homo sapiens* to use imagination. What is certain is that hunting and gathering was a way of life for 10,000 years until people formed settlements after the Ice Age and cities began to emerge. ●

Human Evolution

Perhaps motivated by climatic change, some five million years ago the species of primates that inhabited the African rainforest subdivided, making room for the appearance of the hominins, our first bipedal ancestors. From that time onward, the scientific community has tried to reconstruct complex phylogenetic trees to give an account of the rise of our species. DNA studies on fossil remains allow us to determine their age and their links with different species. Each new finding can put into question old theories about the origin of humans. ●

Primates That Talk

The rise of symbolic language, which is a unique ability of humans, is a mystery. But the evolution of the speech apparatus in humans has been decisive. The human larynx is located much lower than in the rest of the mammals. This characteristic makes it possible to emit a much greater variety of sounds.

THE PHYLOGENETIC TREE

This cladogram (map of emergence of new species from previous ones) shows the relationship of the *Homo* genus to the other species of primates.

Gorillas, chimpanzees, and hominins had a common ancestor at least five million years ago.

NOT-SO-DISTANT RELATIVES

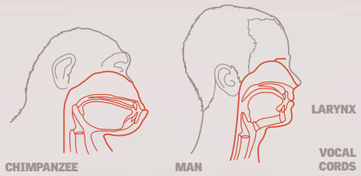
There are various uncertainties and disagreements among paleontologists about how the evolutionary tree for hominins branches out. This version is based on one created by paleoanthropologist Ian Tattersall.

FUNCTION OF SPEECH

In humans, speech has a semantic character. Upon speaking, a human always addresses other people with the object of influencing them, changing their thoughts, enriching them mentally, or directing their conduct toward something specific. Some scientists believe that a change in the brain or vocal apparatus allowed the development of complex language, which facilitated creativity and the acquisition of knowledge.

TOOLS FOR SPEAKING

The larynx of humans is located much lower than in chimpanzees and thus allows humans to emit a greater variety of sounds.



AND FOR THINKING

The evolution of the brain has been essential for the development of language and other human capacities. Greater cranial capacity and nutrition have had physiological influences.

Australopithecus

PRECURSOR

This ape was the first true hominin but is extinct today.

UPRIGHT POSTURE

Walking on two legs led to a weakening of the neck muscles and a strengthening of the hip muscles.

FREE ARMS

BIPEDALISM

requires less energy to move and leaves the hands free.

Homo habilis

THE GREAT LEAP

Its brain was much greater, and there were substantial anatomical changes.

GROWTH

It is calculated that the growth of the brain is 44 percent larger with respect to *Australopithecus*, an enormous development in relation to the body.

ABILITY

It already was using sticks and rocks as tools.

BONES

Those of the hands and legs are very similar to those of modern human beings.

Homo erectus

MIGRANT

This is the species that left Africa and rapidly populated almost all the Old World. From the form of its larynx, it is deduced that *Homo erectus* could talk.

MUSCLES

Some prominent muscle markings and thick reinforced areas of the bones indicate that the body of *H. erectus* could support strong movement and muscle tension.

THICKNESS

Its bones, including the cranium, were thicker than those in previous species.

SIZE

It already had the stature of *Homo sapiens* but was stronger.

Homo neanderthalensis

HUNTER-GATHERER

Very similar to *H. sapiens*; nevertheless, it is not its ancestor, but a species that emerged from *H. erectus*.

CHEST

The rib cage opened slightly outward.

ADAPTATION

Its short, robust physique shows good adaptation to cold climates.

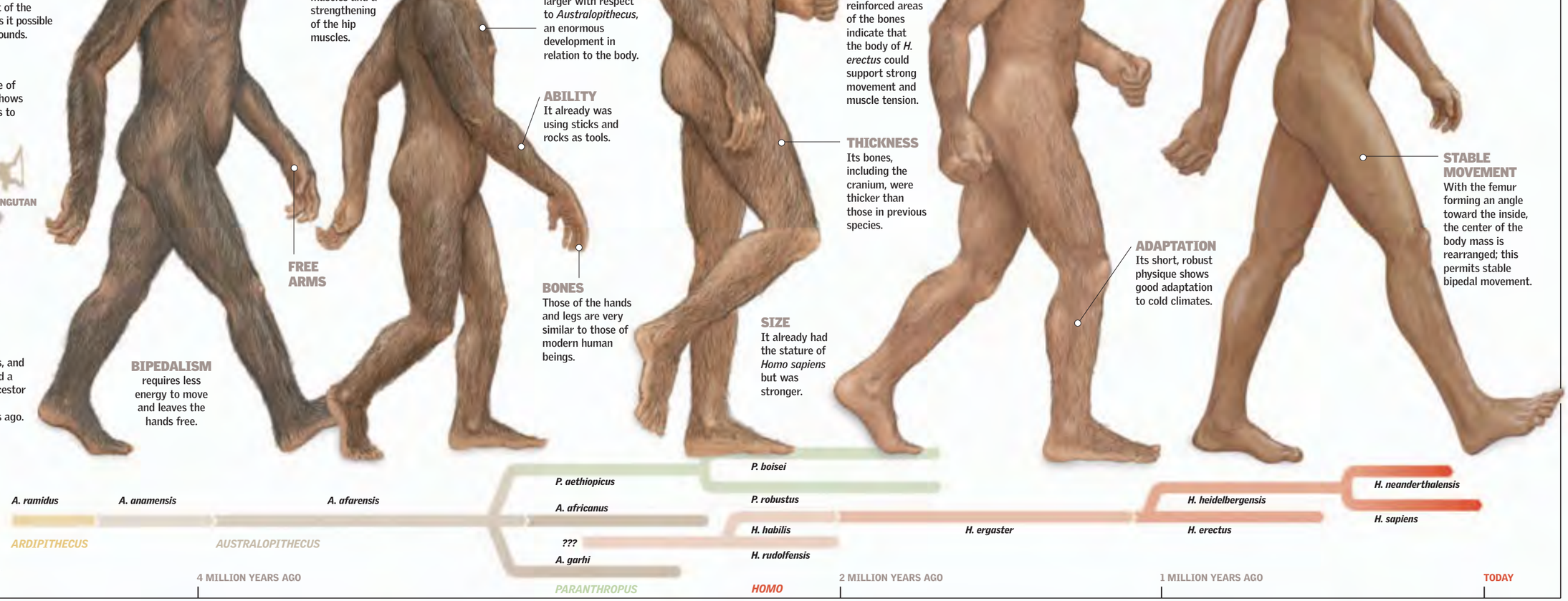
Homo sapiens

CULTURAL ANIMAL

The only surviving species of the *Homo* genus. Its evolution took place not through genetics but through culture.

STABLE MOVEMENT

With the femur forming an angle toward the inside, the center of the body mass is rearranged; this permits stable bipedal movement.



First Humans

The *Australopithecus* were the first humanlike creatures who could walk in an upright posture with their hands free, as indicated by the fossils found in Tanzania and Ethiopia. It is believed that climatic changes, nutritional adaptations, and energy storage for movement contributed to bipedalism. In any case, their short legs and long arms are seen as indications that they were only occasional walkers. Their cranium was very different from ours, and their brain was the size of a chimpanzee's. There is no proof that they used stone tools. Perhaps they made simple tools with sticks, but they lacked the intelligence to make more sophisticated utensils.

Adaptation to the Environment

The climatic changes that occurred during the Miocene probably transformed the tropical rainforest into savannah. Various species of hominins left their habitats in the trees and went down to the grasslands in search of food. It is conjectured that the first hominins began to stand up to see over the grasslands.

SPECIAL TEETH
They had large incisors like spatulas in front, and the teeth became arranged in the form of an arch.

BIPEDALISM
By walking on two feet, they were able to free their upper limbs while they moved.

DORSAL SPINE
had many curves to maintain balance. Given that monkeys do not have lumbars, the weight of the body falls forward.

ADAPTED PELVIS
Morphological changes in the pelvis, sacrum, and femur made these bones similar to those in modern humans.

TOE
Whereas in chimpanzees the big toe is used to grasp, the position of the big toe and the foot arch in hominins supported movement in a bipedal posture.

KNEE
Unlike chimpanzees, the rim of the femur had an elliptical shape like that in the human knee.

AUSTRALOPITHECUS AFARENSIS

Archaeological Findings

The fossil skull of a child was found in 1924 in the Taung mine (South Africa). The remains included the face with a jaw and tooth fragments as well as skull bones. The brain cavity had been replaced with fossilized minerals. Later, in 1975, footprints of hominins were found in Laetoli (Tanzania). It is believed that more than three million years ago, after a rain that followed a volcanic eruption, various specimens left their tracks in the moist volcanic ash.

SKULL OF TAUNG
Had a round head and strong jaw. Its cranial cavity could house a brain (adult) of 26 cubic inches (440 cu cm).

2.5 million years ago

LAETOLI
In 1975 in Laetoli (Tanzania), tracks of hominins that archaeologists found in fossilized volcanic ash provided evidence of hominins walking on two legs (bipedalism).

3.6 million years ago

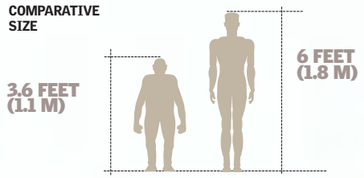
AUSTRALOPITHECUS AFARENSIS

AUSTRALOPITHECUS ANAMENSIS ***PARANTHROPUS AETHIOPICUS*** ***AUSTRALOPITHECUS AFRICANUS*** ***PARANTHROPUS ROBUSTUS*** ***PARANTHROPUS BOISEI***

Australopithecus afarensis

Considered the oldest hominin, it inhabited eastern Africa between three and four million years ago. A key aspect in human evolution was the bipedalism achieved by *A. afarensis*. The skeleton of "Lucy," found in 1974, was notable for its age and completeness.

3 million years ago



THE SKELETON OF LUCY
This hominid found in Ethiopia had the size of a chimpanzee, but its pelvis allowed it to maintain an upright position.

Image reconstructed from the bones of Lucy.

AUSTRALOPITHECUS ANAMENSIS
4.2 to 3.9 million years ago. Primitive hominin with wide molars.

AUSTRALOPITHECUS AFRICANUS
3 to 2.5 million years ago. Globular skull with greater cerebral capacity.

PARANTHROPUS AETHIOPICUS
Approximately 2.5 million years ago. Robust skull and solid face.

PARANTHROPUS BOISEI
2.2 to 1.3 million years ago. Skull adapted for consumption of tough vegetables.

PARANTHROPUS ROBUSTUS
1.8 to 1.5 million years ago. Very robust, bony appearance.

Use of Tools

The emergence of *Homo habilis*, which had a more humanlike appearance than *Australopithecus*, in eastern Africa showed important anatomical modifications that allowed advancement, especially in the creation of various stone tools, such as flaked pebbles for cutting and scraping and even hand axes. The bipedal posture for locomotion was established, and the first signs of language appeared. Stone technology became possible thanks to the notable increase in brain size in *Homo habilis*. In turn, the anatomic development of *Homo erectus* facilitated its migration toward areas far from its African origins, and it appears to have populated Europe and Asia, where it traveled as far as the Pacific Ocean. *Homo erectus* was capable of discovering fire, a vital element that improved human nutrition and provided protection from the cold.

Homo habilis

The appearance of *Homo habilis* in eastern Africa between 2 and 1.5 million years ago marked a significant advancement in the evolution of the human genus. The increased brain size and other anatomical changes together with the development of stone technology were substantive developments in this species, whose name means "handy man." Although it fed on carrion, it was still not capable of hunting on its own.

THE BRAIN

The cranial cavity of *Homo habilis* was larger than that of *Australopithecus*, reaching a cerebral development of between 40 and 50 cubic inches (650-800 cu cm). It is believed that this characteristic was key in developing the capacity of making tools, considering that it had half the brain size of modern humans.

1

CARVING

The first step was to select rocks and scrape them until sharp.

2

REMOVING

A "stone hammer" was used to sharpen the edges of the tools.

THIS CARVED ROCK IS THE OLDEST KNOWN TOOL.

MAP OF LOCATIONS AND MIGRATIONS

ARCHAEOLOGICAL FINDINGS

The first being known as *Homo habilis* was found in 1964 in the Olduvai Gorge, located in the Serengeti Plain (Tanzania). The later discovery of the Turkana Boy (Kenya) revealed many of the physical particularities of *Homo erectus*.

SKULL OF *HOMO HABILIS* FOUND IN OLDUVAI (TANZANIA)

SKULL OF *HOMO ERECTUS* FOUND IN KOOBI FORA (KENYA)

FIRE

One of the major discoveries in the evolution of humans. It was used not only for protection from the cold but also to treat wood and cook food. The first evidence of the use of fire is some 1,500,000 years ago.

HOMO ERECTUS

HAND AX IN THE SHAPE OF A DROP

HOMO HABILIS *HOMO ERECTUS*

Homo erectus

The "erect man" is native to East Africa, and its age is estimated at 1.8 million years. It was the first hominin to leave Africa. In a short time it populated a great part of Europe. In Asia it reached China to the east and the island of Java to the southeast. Much of what is known about this species was learned from a finding called Turkana Boy near Lake Turkana, Kenya, in 1984. This species was tall and had long limbs. The brain of this specimen was larger than that of *Homo habilis*, and it could have made the fundamental discovery of making fire.

COMPARATIVE SIZES

HOMO HABILIS	*HOMO ERECTUS*	*HOMO SAPIENS*
5 FEET (1.3 M)	5.3 FEET (1.6 M)	6 FEET (1.8 M)

2.5 MILLION YEARS AGO

Appearance of *Homo habilis* in eastern Africa.

1.7 MILLION YEARS AGO

Homo erectus is the first hominin to leave its habitat.

1.6 MILLION YEARS AGO

Homo habilis disappears because of unknown causes.

ABOUT 1.5 MILLION YEARS AGO

First use of fire by *Homo erectus*, in southern Africa

Able Hunters

Descendants of *Homo heidelbergensis*, the Neanderthals were the first inhabitants of Europe, western Asia, and northern Africa. Diverse genetic studies have tried to determine whether it is a subspecies of *Homo sapiens* or a separate species. According to fossil evidence, Neanderthals were the first humans to adapt to the extreme climate of the glacial era, to carry out funerals, and to care for sick individuals. With a brain capacity as large or larger than that of present-day humans, Neanderthals were able to develop tools in the style of the Mousterian culture. The cause of their extinction is still under debate.

MAP OF SITES

HOMO NEANDERTHALENSIS

HOMO HEIDELBERGENSIS

Homo neanderthalensis

The Middle Paleolithic (400,000 to 30,000 years ago) is dominated by the development of *Homo neanderthalensis*. In the context of the Mousterian culture, researchers have found traces of the first use of caves and other shelters for refuge from the cold. Hunters by nature, *H. neanderthalensis* created tools and diverse utensils, such as wooden hunting weapons with sharpened stone points.

THE AGE OF SOME NEANDERTHAL DISCOVERIES

They lived in

shelters made of mammoth bones and covered with skins.

Graves

Much is known about the *Neanderthals* because they buried their dead.

MAN—HUNTER

Males were dedicated to the search for food, while the women looked after children. It is believed that Neanderthals hunted large prey over short distances. They used wooden spears with stone points and probably jumped on the prey.

100,000 years ago
TOOLS FOUND

Rocks for cutting and scraping

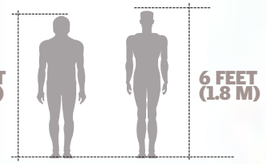
Tools for tanning hides

Humans of the Ice Age

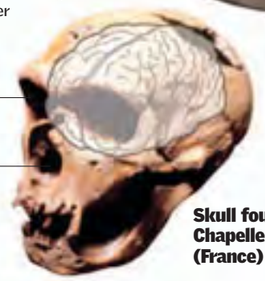
Characterized as the caveman of the Ice Age, *Homo neanderthalensis* was able to use fire and diverse tools that allowed it to work wood, skins, and stones, among other materials. They used the skins to cover themselves from cold and to build shelter, and the stones and the wood were key materials in the weapons used for hunting. The bone structure of their fossils reveals a skull with prominent ciliary arcs, sunken eyes, a wide nose, and large upper teeth, probably used to grasp skins and other objects during the process of rudimentary manufacture.

PHYSICAL CONTEXT
The bones in the hand made it possible to grasp objects much more strongly than modern man can.

COMPARATIVE SIZE



GREATER CRANIAL CAPACITY
In comparison to modern humans, Neanderthals had a larger brain capacity.



Skull found in La Chapelle-aux-Saints (France)

98 cubic inches
(1,600 cu cm) cranial capacity

600,000 YEARS AGO

Homo heildebergensis is in Europe, part of Asia, and Africa.

400,000 YEARS AGO

Wooden spears found in Germany and the United Kingdom date back to this time.

150,000 YEARS AGO

Homo neanderthalensis lives in the Ice Age in Europe and western Asia.

160,000 YEARS AGO

First *Homo sapiens* found in Africa

25,000 YEARS AGO

Homo neanderthalensis becomes extinct from unknown causes.

Direct Ancestors

The origin of the human species is still in debate, even though scientists have been able to establish that *H. sapiens* is not directly related to the Neanderthals. The most accepted scientific studies for dating Neanderthal fossils places the oldest specimens some 195,000 years ago in Africa. New genetic studies based on mitochondrial DNA have corroborated that date and have also contributed to determining the possible migration routes that permitted the slow expansion of *H. sapiens* to other continents. Meanwhile, the new discoveries raise unanswered questions about what happened in the course of the 150,000 years that preceded the great cultural revolution that characterizes *H. sapiens* and that occurred some 40,000 years ago with the appearance of Cro-Magnon in Europe.

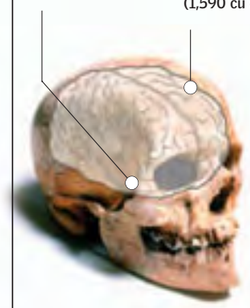
Homo sapiens sapiens

It is believed that Cro-Magnon arrived in Europe some 40,000 years ago. Evidence of prehistoric art, symbolism, and ritual ceremonies distinguish this advanced culture from other species of hominins that preceded it. It was well-adapted to its environment, lived in caves, and developed techniques of hunting in groups. It captured large animals with traps and small ones with rocks.

TOOLS
Homo sapiens invented multiple tools for various uses and were usually made from stone, bone, horns, and wood.

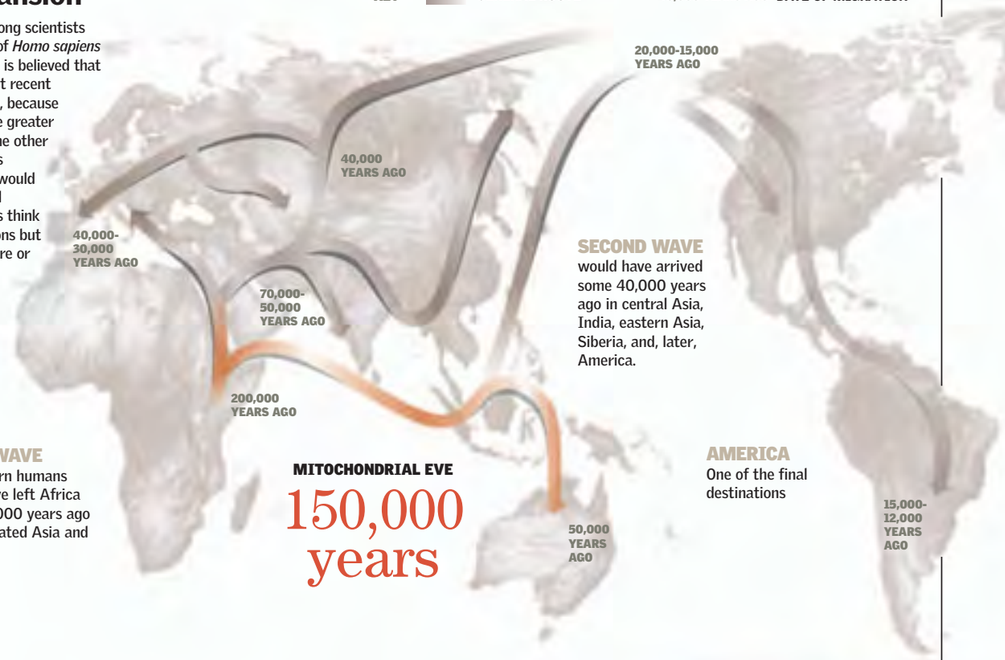
EVOLUTION OF THE SKULL
Cro-Magnon had a small face, high forehead, and longer chin.

CRANIAL CAPACITY
Its cranial cavity could hold a brain of up to 97 cubic inches (1,590 cu cm).



Theories of Expansion

There is no agreement among scientists about how the expansion of *Homo sapiens* to the entire world took place. It is believed that the "Mitochondrial Eve," the most recent common ancestor, lived in Africa, because the people of that continent have greater genetic diversity than those of the other continents. From there, in various migratory waves, *Homo sapiens* would have reached Asia, Australia, and Europe. However, some scientists think that there were no such migrations but that modern humans evolved more or less simultaneously in various regions of the ancient world.



FIRST WAVE
The modern humans would have left Africa some 60,000 years ago and populated Asia and Australia.

SECOND WAVE
would have arrived some 40,000 years ago in central Asia, India, eastern Asia, Siberia, and, later, America.

AMERICA
One of the final destinations

AFRICAN CRADLE
The majority of paleoanthropologists and geneticists agree that humans of today emerged in Africa. It is there they have found the oldest bones.

Out of Africa

According to this theory, modern man is an evolution of the archaic *Homo sapiens* that emerged in Africa. From there it would have extended to the rest of the world, overrunning the Neanderthals and primitive *Homo sapiens*. The anatomical differences between the races would have occurred in the last 40,000 years.

Multiregional Evolution

The theory of regional continuity, or multiregional evolution, states that the modern human developed simultaneously in diverse regions of the world, like the evolution of local archaic *Homo sapiens*. The last common ancestor would be a primitive *Homo erectus* that lived in Africa some 1.8 million years ago.

150,000 YEARS AGO
The "Mitochondrial Eve" is the common ancestor of all people.

120,000 YEARS AGO
Homo sapiens begins to extend through Africa.

90,000 YEARS AGO
"Nuclear Adam" was the common ancestor of all the men of the world.

60,000 YEARS AGO
Traces of *Homo sapiens* in China

40,000 YEARS AGO
Cro-Magnon (type of *Homo sapiens*) appears in Europe.

Culture, the Great Leap

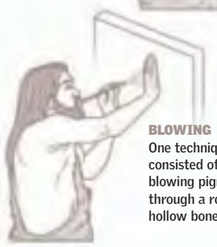
Although questions remain about how culture originated, it is almost impossible to determine which things of the human world are natural and which are not. Scientists of many disciplines are trying to answer these questions from the evidence of prehistoric life found by paleontologists. The subspecies of mammals to which man belongs, *Homo sapiens sapiens,* appeared in Africa some 150,000 years ago, disseminated through the entire Old World some 30,000 years ago (date that the oldest signs of art were found), and colonized America 11,000 years ago; but the first traces of agriculture, industry, population centers, and control over nature date from barely the last 10,000 years. Some believe that the definitive leap toward culture was achieved through the acquisition of a creative language capable of expressing ideas and sentiments more advanced than the simple communication of *Homo erectus.*

The first artists

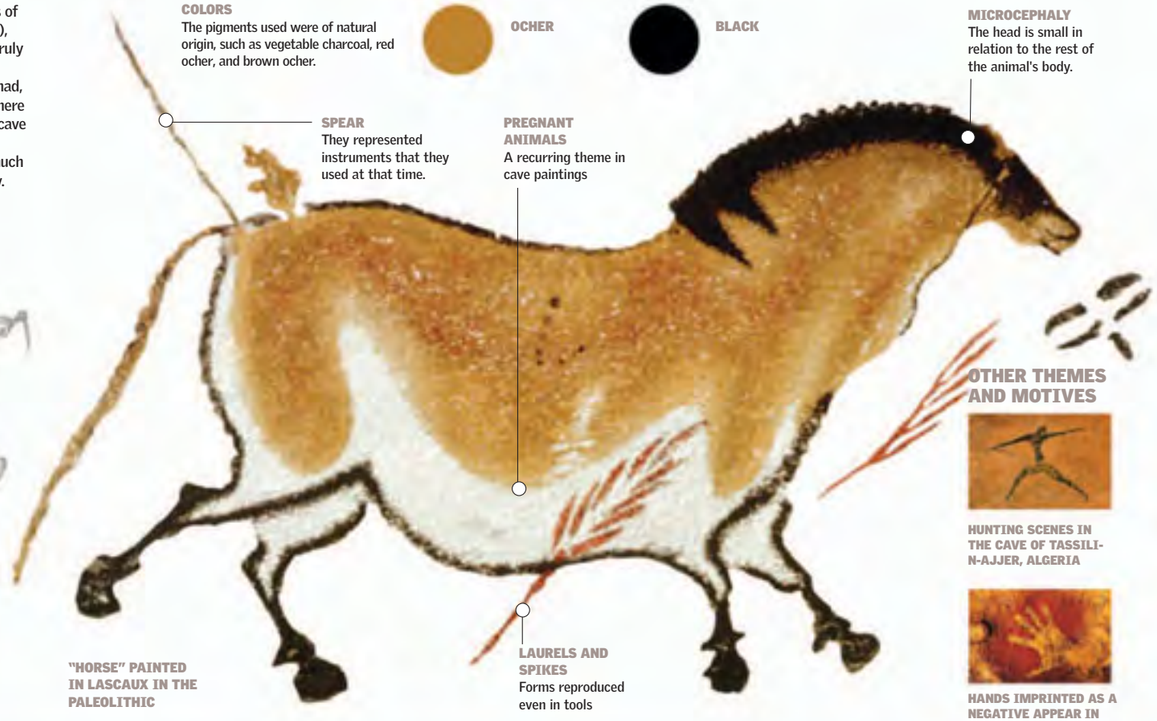
Cave paintings, like those of the caves of Altamira (Spain) and Lascaux (France), leave no doubt that those who made them truly possessed the attributes of human beings. Architecture had not arrived, but paintings had, engraved and sculptured in stone or bone. There exist various theories about the function of cave painting that consider the aesthetic, the magical, the social, and the religious—not much different from the questions about art today.

CAVE-PAINTING TECHNIQUES

GEOMETRIC DESIGNS
Dotted and lineal geometric designs, along with mythical chimeras, have been found among European cave paintings similar to the rock art of Aboriginal Australians.



BLOWING
One technique consisted of blowing pigment through a rod or hollow bone.



COLORS
The pigments used were of natural origin, such as vegetable charcoal, red ocher, and brown ocher.

OCHER

BLACK

SPEAR
They represented instruments that they used at that time.

PREGNANT ANIMALS
A recurring theme in cave paintings

LAURELS AND SPIKES
Forms reproduced even in tools

"HORSE" PAINTED IN LASCAUX IN THE PALEOLITHIC

OTHER THEMES AND MOTIVES

HUNTING SCENES IN THE CAVE OF TASSILI-N-AJJER, ALGERIA

HANDS IMPRINTED AS A NEGATIVE APPEAR IN MULTIPLE PLACES.

MICROCEPHALY
The head is small in relation to the rest of the animal's body.

ART ON THE WALLS

Cave painting is a phenomenon that was found mainly in the current regions of France and Spain. In France, there are more than 130 caves; the most famous are located in the Aquitaine region (Lascaux, Pech-Merle, Laugerie, La Madeleine) and in the Pyrenees (Niaux, Le Tucs d'Audubert, Bedeilhac). Spain has some 60 caves in the Cantabria region to the north, among them the cave of Altamira, and 180 caves farther south. Examples from other regions include caves at Addaura, Italy, and Kapova, Russia. Portable art, on the other hand, was abundant in all Europe.

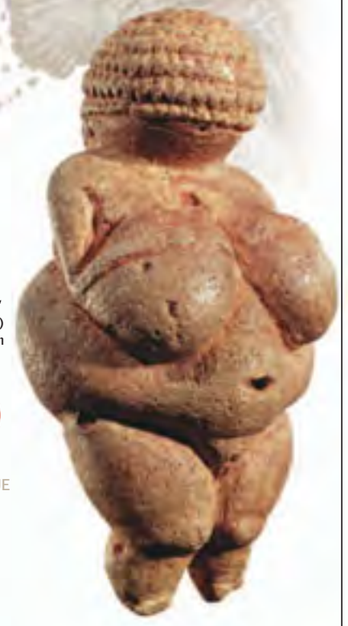
14,000 years old
THE PAINTINGS OF ALTAMIRA

Builders of objects

Homo sapiens sapiens distinguished itself from its ancestors, who were already making rudimentary tools, through the growing use of such new materials as bone and above all for the specialization of new tools. Mortars, knives, boring tools, and axes had forms and functions continually more sophisticated. There also appeared, in addition to utensils and tools, objects with ornamental and representative functions that attested to humans' increasing capacity for symbolism. These manifestations, through which the art could leave the caves, are known as portable art. It produced objects that were utilitarian, luxurious, or ceremonial, like the Paleolithic "Venus" figurines.

SYMBOLISM
The "Venus of Willendorf" measures 4 inches (11 cm) in height and was found in Austria.

24,000 years old
IS THIS LITTLE STATUE



PALEOLITHIC TOOLS

TWO-SIDED KNIFE
Its invention presaged the most important cultural revolution of the Upper Paleolithic.

HARPOON
This complex instrument of bone dates from some 11,000 years ago (Magdalenian Period, France).

POLISHED AX
Found in Wetzlar, Germany, it shows the polishing technique of 20,000 years ago.

WÜRM GLACIATION 35,000 YEARS
The Upper Paleolithic begins.

AURIGNACIAN 30,000 YEARS AGO
Tools of mammoth tusk, flake tools

PERIGORDIAN 27,000 YEARS AGO
Well-cut tools, including a multiangle graver

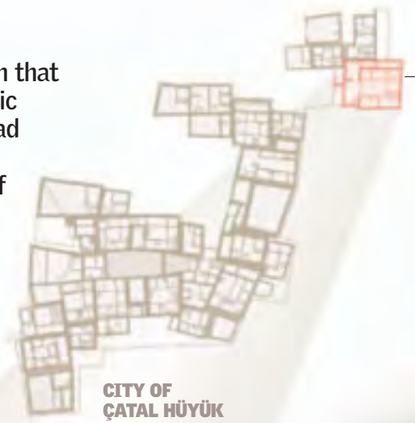
SOLUTREAN 20,000-50,000 YEARS AGO
Use of oxide to paint, pointed instruments

MAGDALENIAN 15,000 YEARS AGO
The greatest flourishing of cave art in southern Europe

END OF PALEOLITHIC 9,000 BC
End of the glaciations, with an improvement of the global climate

Urban Revolution

Some 10,000 years ago, there was an interglacial period on Earth that caused a gradual increase in temperatures and an overall climatic change that brought a modification to the life of humans. Instead of roaming from place to place to hunt, people began to create societies based on sedentary life, agriculture, and the domestication of animals. Some villages grew so much that they became true cities, such as Çatal Hüyük in southern Turkey. In the ruins of this city, considered one of the milestones of modern archaeology, were found a good number of ceramics and statues of the so-called mother goddess—a woman giving birth—that belonged to a fertility ritual. In addition, there are signs that the inhabitants practiced funeral rights and built dolmens for collective graves.



CITY OF ÇATAL HÜYÜK

LOCATION OF ÇATAL HÜYÜK

Country	Turkey
Year	7000 BC
Type of City	Farming-livestock

CROPS
In the fields near Çatal Hüyük, the inhabitants grew wheat, sorghum, peas, and lentils. They gathered apples, pistachios, and almonds.

LENTILS

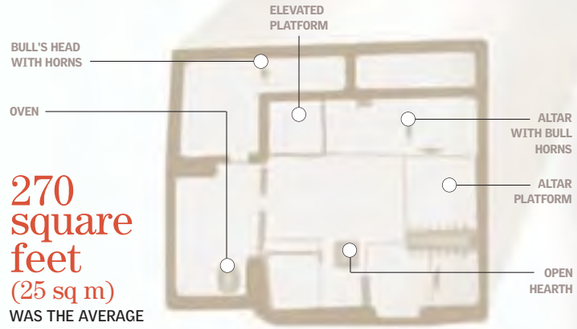
APPLES

WHEAT

6,000 years BC ÇATAL HÜYÜK WAS ONE OF THE FIRST CITIES.

The Neolithic City of Çatal Hüyük

Çatal Hüyük is located in southern Anatolia (Turkey). Houses were built side by side, sharing a common wall. There were no exterior windows or openings, and the buildings had flat-terraced roofs. People entered through the roof, and there were usually one or two stories. The walls and terraces were made of plaster and then painted red. In some main residences, there were paintings on the walls and roof. The houses were made of mud bricks and had a sanctuary dedicated to the mother goddess. During the excavation, many religious articles were uncovered: the majority were ceramic figures in relief depicting the mother goddess and heads of bulls and leopards.



270 square feet (25 sq m) WAS THE AVERAGE SIZE OF A HOUSE

MOTHER GODDESS

CULTS
There is a direct relationship between the emergence of agriculture and the cult of the feminine because of the importance of fertility. Statuettes of pregnant women were found in homes in shrines decorated with molded bull heads and other figures.

OTHER TYPES OF CONSTRUCTION

The process of carrying out a megalithic construction began in a quarry, where large blocks of stone were extracted.

1 Transport
The stones were transported on rollers to the place chosen for the erection of the monument.

2 Erection
The blocks were dropped into a hole and placed in a vertical position.

3 Earthworks
Embankments were made for the construction of a dolmen.

4 Trilith
The horizontal block was transported over an embankment and placed on the two upright stones.

8000 BC
First indications of agricultural activities

7000 BC
Expansion of agriculture. Complex funerary rites.

6000 BC
Stable settlements in the Persian Gulf

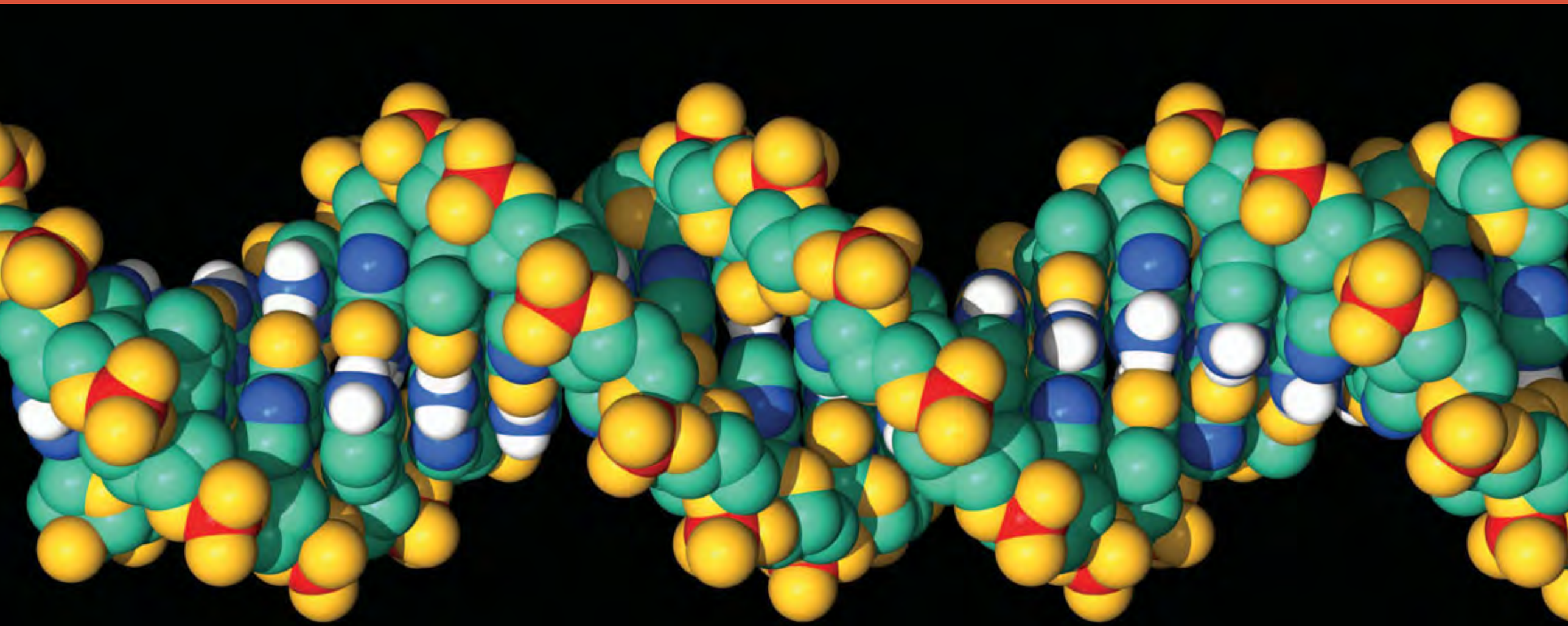
3500 BC
Invention of writing in Mesopotamia

AD 320
First vehicles with wheels in Asia.

Mechanisms of Heredity

DNA
Complex macromolecule that contains a chemical code for all the information necessary for life

SELF-COPYING 56-57
THE CHROMOSOME 58-59
THE REPLICATION OF LIFE 60-61
TRANSCRIPTION OF THE GENETIC CODE 62-63
THE PATH OF THE GENE 64-65
PROBLEMS OF HEREDITY 66-67



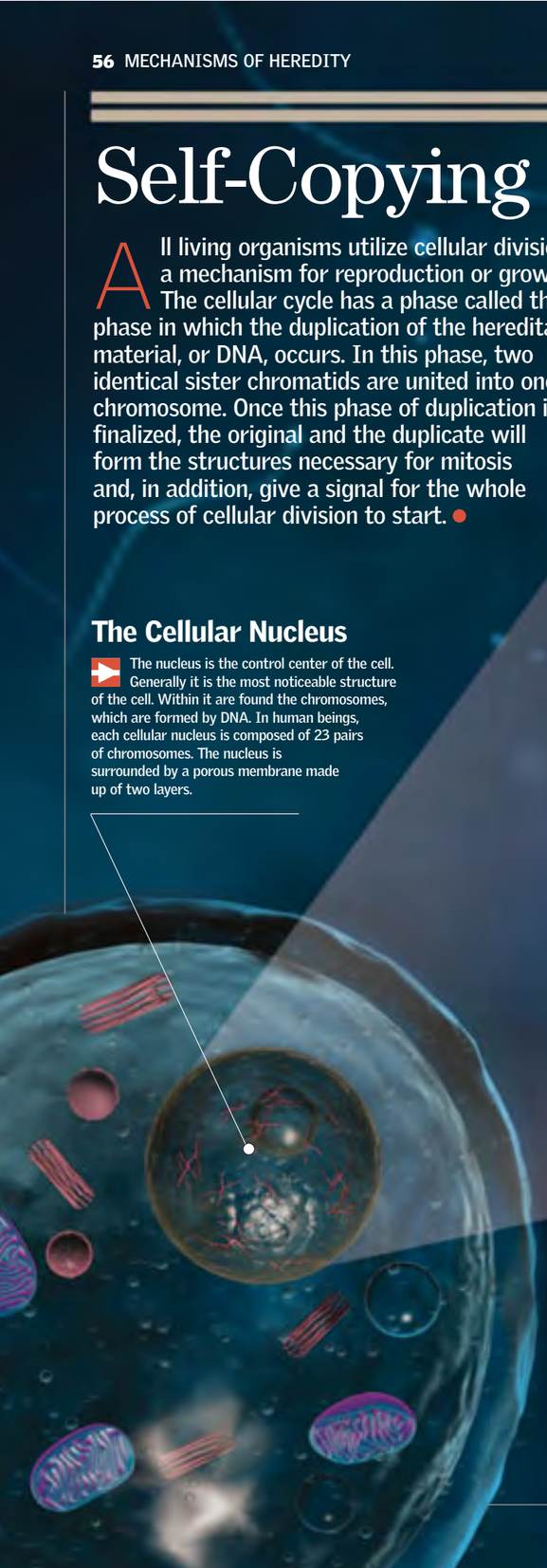
The cells of the body are constantly dividing to replace damaged cells. Before a cell divides to create new cells, a process known as mitosis, or to form ovules or spermatozoa, a process called meiosis, the DNA included in each cell needs to copy, or replicate, itself. This process is possible because the DNA strands can open and separate. Each of the two strands of the original DNA serves as a model for a new strand. In this chapter, we will also tell you how human beings vary in height, weight, skin color, eyes, and other physical characteristics despite belonging to the same species. The secret is in the genes, and we will show it to you in a simple way. ●

Self-Copying

All living organisms utilize cellular division as a mechanism for reproduction or growth. The cellular cycle has a phase called the S phase in which the duplication of the hereditary material, or DNA, occurs. In this phase, two identical sister chromatids are united into one chromosome. Once this phase of duplication is finalized, the original and the duplicate will form the structures necessary for mitosis and, in addition, give a signal for the whole process of cellular division to start.

The Cellular Nucleus

The nucleus is the control center of the cell. Generally it is the most noticeable structure of the cell. Within it are found the chromosomes, which are formed by DNA. In human beings, each cellular nucleus is composed of 23 pairs of chromosomes. The nucleus is surrounded by a porous membrane made up of two layers.



GROWTH AND CELLULAR DIVISION

The cellular cycle includes cell growth, in which the cell increases in mass and duplicates its organelles, and cell division, in which DNA is replicated and the nuclei divide.

1

PHASE G1
The cell doubles in size. The number of organelles, enzymes, and other molecules increases.

2

S PHASE
The DNA and associated proteins are copied, resulting in two copies of the genetic information.

3

PHASE G2
The chromosomes begin to condense. The cell prepares for division.

4

MITOSIS
The two sets of chromosomes are distributed, one set for each nucleus of the two daughter cells.

5

CYTOKINESIS
The cytoplasm of the mother cell divides and gives rise to two daughter cells identical to the mother.

History of the Chromosome

The chromosomes carry the genetic information that controls the characteristics of a human being, which are passed from the parents to the children and from generation to generation. They were discovered by Karl Wilhelm von Nägeli in 1842. In 1910 Thomas Hunt Morgan discovered the primordial function of the chromosomes: he called them carriers of genes. Thanks to demonstrating this, Morgan received the Nobel Prize for Physiology or Medicine in 1933.

HOW THEY LOOK

Once they have duplicated, the chromosomes form a structure in the shape of a cross. In this structure, the centromere functions as the point of union for the chromatids.

6.5 feet (2 m)
LENGTH OF DNA IN HUMAN CELL CHROMOSOMES

46 chromosomes
HUMAN BEING

AMOUNT OF CHROMOSOMES ACCORDING TO SPECIES

The number of chromosomes of a species varies independently of its size and complexity. A fern has thousands of chromosomes and a fly only a few pairs.

8 chromosomes
FRUIT FLY

24 chromosomes
SALAMANDER

1,262 chromosomes
FERNS

The Chromosome

The chromosome is a structural unit that consists of a molecule of DNA associated with proteins. Eukaryote chromosomes condense during mitosis and meiosis and form structures visible through a microscope. They are made of DNA (deoxyribonucleic acid), RNA (ribonucleic acid), and proteins. The majority of the proteins are histones, small positively charged molecules. Chromosomes carry the genes, the functional structures responsible for the characteristics of each individual.

Karyotype

The ordering and systematic classification of the chromosomes by pairs, size, and position of the centromere. The chromosomes that are seen in a karyotype are found in the metaphase of mitosis. Each one of them consists of two sister chromatids united by their centromeres.

1

CHROMATINS
There are two types: euchromatin, lightly packed, and heterochromatin, more densely packed. The majority of nuclear chromatin consists of euchromatin.

Carrier of Genes

In the DNA, certain segments of the molecule are called genes. These segments have the genetic information that will determine the characteristics of an individual or will permit the synthesis of a certain protein. The information necessary for generating the entire organism is found in each cell, but only the part of the information necessary for reproducing this specific type of cell is activated. The reading and transmission of the information for use outside the nucleus is performed by messenger RNA.

2

THE FRAMEWORK
Each one of the rosettes consists of loops stabilized by the "scaffolding" of other proteins. These loops help to condense the chromatin.

6
loops
IN EACH ROSETTE

30
rosettes
IN EACH TURN OF THE SPIRAL

6
nucleosomes
IN EACH TURN

3

SOLENOID
A group of six nucleosomes that form each turn inside the loops

0.0000012 inch
(0.00003 mm)
DIAMETER OF EACH SOLENOID

SPACER DNA
The nucleosomes are united by chains of base pairs of DNA 0.0000004 inch (0.00001 mm) long.

PEARL NECKLACE
If the DNA chain is stretched and observed under a microscope, it resembles beads on a string. Nevertheless, DNA chains are generally found pressed very tightly around the nucleus.

60
base pairs
THE AMOUNT OF DNA BETWEEN NUCLEOSOMES

4

NUCLEOSOME
A group of eight histone molecules with two DNA spirals twisted around them. The "tails" of the histones seem to interact with the molecules that regulate genetic activity.

NITROGEN BASES

CIRCULAR CHROMOSOME OF BACTERIA

PROKARYOTE CELL
Prokaryote cells do not have a cellular nucleus, so the DNA is found in the cytoplasm. The size of the DNA differs according to species. Prokaryotes are almost all unicellular organisms belonging to the domains of the archaea and bacteria.

The Replication of Life

In deoxyribonucleic acid—DNA—all the genetic information of a complete organism is found. It has complete control of heredity. A DNA molecule consists of two strands of relatively simple compounds called nucleotides. Each nucleotide consists of a phosphate, sugar, and one of four kinds of nitrogenous bases. The nucleotides on each strand are paired in specific combinations and connected to each other by hydrogen bonds. The two strands coil around each other in the form of a spiral, or double helix.

Complementary

Various specialized proteins called enzymes act as biological catalysts, accelerating the reactions of replication: helicase, which is in charge of opening the double helix of DNA; polymerase, which is in charge of synthesizing the new strands of DNA in one direction; and ligase, which seals and joins the fragments of DNA that were synthesized.

50
nucleotides
PER SECOND IS THE SPEED OF DNA REPLICATION IN HUMANS.

NEW CHAIN

REPLICATION

The genetic information is encoded in the sequence of the bases of the DNA nucleotides aligned along the DNA molecule. The specificity of the pairing of these bases is the key to the replication of DNA. There are only two possible combinations—thymine with adenine and guanine with cytosine—to form the complementary links of the strands that make up the DNA chain.

ORIGINAL CHAIN

1

WEAK BRIDGES

Helicase separates the double helix, thus initiating the replication of both chains. The chains serve as a model to make a new double helix.

ORIGINAL

COPY

BASIC MECHANISM

The new bases join to make a DNA chain that is a daughter of the previous model.

2

FREED ENERGY

The energy to form new links is obtained from the phosphate groups. The free nitrogenous bases are found in the form of triphosphates. The separation of the phosphates provides the energy to interlace the nucleotides in the new chain that is being built.

3

NEW CONNECTION

The new chains of DNA couple in short segments, and the ligase joins them to form the daughter molecules.

4

PERFECT REPLICATION

The result is two new molecules, each with one strand from the original DNA and one new complementary strand. This is called semiconservative replication. The genetic information of the new strand is identical to that of the original DNA molecule.

Nucleotides

The nucleotides have three subunits: a phosphate group, a five-carbon sugar, and a nitrogenous base. In DNA these bases are small organic molecules. Adenine and guanine are purines, and cytosine and thymine are pyrimidines, smaller than the purines. All are composed of nitrogen, hydrogen, carbon, and oxygen—except for adenine, which has no oxygen. The adenine is always paired with thymine and guanine with cytosine. The first pair is joined by two hydrogen bonds and the second by three.

GUANINE

ADENINE

HYDROGEN BOND

CYTOSINE

THYMINE

Biological Revolution

Deciphering the molecular structure of DNA was the major triumph of biomolecular studies in biology. Based on work by Rosalind Franklin on the diffraction of X-rays by DNA, James Watson and Francis Crick demonstrated the double-helix composition of DNA in 1953 and for their work won the 1962 Nobel Prize for Physiology or Medicine.

DNA TRANSCRIPTION

The process of copying one simple chain of DNA is called transcription. For it to happen, the double strands separate through the action of an enzyme, permitting the enzyme RNA polymerase to connect to one of the strands. Then, using the DNA strand as a model, the enzyme begins synthesizing messenger RNA from the free nitrogenous bases that are found inside the nucleus.

30
bases per second
ARE COPIED DURING THE PROCESS OF TRANSCRIPTION.

Transcription of the Genetic Code

This complex process of translation allows the information stored in nuclear DNA to arrive at the organelles of the cell to conduct the synthesis of polypeptides. RNA (ribonucleic acid) is key to this process. The mRNA (messenger RNA) is in charge of carrying information transcribed from the nucleus as a simple chain of bases to the ribosome. The ribosome, together with transfer RNA (tRNA), translates the mRNA and assembles surrounding amino acids following the genetic instructions.

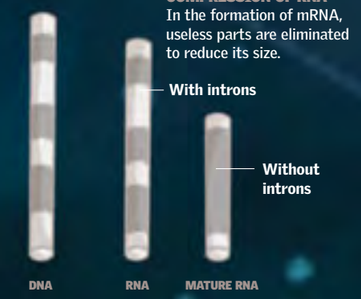
1

SEPARATION OF DNA
When the DNA is to be transcribed, its double chain separates, leaving a sequence of DNA bases free to be newly matched.

2

TRANSCRIPTION
One of the chains, called the transcriptor, is replicated by the addition of free bases in the nucleus through the action of an enzyme called RNA polymerase. The result is a simple chain of mRNA (messenger RNA).

COMPRESSION OF RNA
In the formation of mRNA, useless parts are eliminated to reduce its size.



SYNTHESIS OF POLYPEPTIDES

The polypeptides form when a group of amino acids unite in a chain. For this to happen, the ribosome: translates the information that the mRNA transcribed from the nuclear DNA; codifies the amino acids and their order with the help of tRNA, through the matching of codons and anticodons; and places each amino acid exactly where it belongs.

RIBOSOME
The cellular organelle where the synthesis of polypeptides occurs. It helps translate the information brought by the mRNA.

ENZYMES
collaborate in the formation of the polypeptide chain by making the peptide chains that join the amino acids.

tRNA
Transfer RNA is in charge of recognizing and translating the information that the mRNA contains.

3

LEAVING THE NUCLEUS
If the DNA were to leave the nucleus, it would get corrupted, so it is the mRNA that transcribes the DNA's information in a simple chain, which takes the information to the cytoplasm of the cell.

4

TRANSLATION
In the ribosome the translation of the mRNA to synthesize the polypeptide is initiated with the participation of tRNA.

5

INTERRUPTION
The synthesis is produced between the start codon and the stop codon. Once the chain reaches the stopping point, the ribosome stops synthesizing the polypeptide, and the ribosome releases the polypeptide.

POLYPEPTIDES
are formations of about 10 to 50 amino acids. Each amino acid is considered a peptide.

The Path of the Gene

Sexual differences in the heredity of traits constitute a model known as sex-linked inheritance. The father of genetics was Gregor Mendel. He established the principle of independent segregation, which is possible only when the genes are situated on different chromosomes; if the genes are found on the same chromosome, they are linked, tending to be inherited together. Later Thomas Morgan contributed more evidence of sex-linked inheritance. Today many traits are identified in this model, such as hemophilia and color blindness.

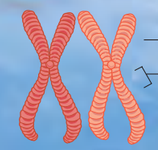
A MEIOSIS I

This first division has four phases, of which prophase 1 is the most characteristic of meiosis, since it encompasses its fundamental processes—pairing and crossing over, which allow the number of chromosomes by the end of this process to be reduced by half.

1
PROPHASE I
The homologous chromosomes pair up, forming chiasmata, which are unique to meiosis.

- CHROMOSOME FROM THE MOTHER
- CHROMOSOME FROM THE FATHER

Linkage
The genes, arranged in linear form and on the same chromosome, are inherited as isolated units.



Crossing Over
Process in which a pair of analogous chromosomes exchange material while they are joined

A CHROMOSOMES DIFFERENTIATED BY THEIR GENES

B INFORMATION CROSSING OVER

C RESULTING PAIR OF CHROMOSOMES

D POSSIBLE COMBINATIONS

CENTROMERE

2
METAPHASE I
The nuclear membrane disappears. The chiasmata, composed of two chromosomes, align, and the centromeres move away.

3
ANAPHASE I
The chiasmata separate. The chromosomes separate from their homologues to incorporate themselves into the nucleus of the daughter cell.

4
TELOPHASE I
The nuclear membranes reform, and the number of chromosomes enclosed in each has been reduced by half.

5
PROPHASE II
The division of the new daughter cells begins: the chromatids condense; the nuclear membranes disintegrate; and the spindles form.

HEREDITY

In human beings, some genes have been identified that are found in the heterochromosomes and deal with sex linkage. For example, the genes that code for hemophilia and color blindness are found in the heterochromosome X.

Gregor Mendel

(1822-84)

POSTULATED THE FIRST LAWS OF INHERITANCE.

B MEIOSIS II

In the second division, the two chromatids that form each chromosome from meiosis I are separated. As a result of this double division, four daughter cells are produced that contain half the characteristic chromosomal number—i.e., 23 chromosomes each (haploid cells). Each chromosome will be composed of a chromatid.

6
METAPHASE II
continues in the daughter cells. The chromosomes align at their middle, and the chromatids affix themselves to the fibers of the spindle.

7
ANAPHASE II
The centromeres divide again, and the sister chromatids divide, going to opposite poles.

8
NUCLEUS OF TELOPHASE
The spindle disappears and forms a membrane around each nucleus.

9
NEW NUCLEI
The new formations have a haploid endowment of chromosomes.

10
CYTOKINESIS
The cytoplasm divides, separating the mother cell into two daughter cells.

1920

THOMAS MORGAN studied the color of eyes in the fly *Drosophilia melangaster.*

Problems of Heredity

Toward the end of the 19th century, the form in which the physical traits of parents were transmitted to their offspring was uncertain. This uncertainty extended to the breeding of plants and animals, which posed a problem for agriculture and livestock producers. In their fields they sowed plants and raised animals without knowing what the quality of their products would be. The work of Gregor Mendel and his contributions to molecular genetics eventually led to a solution to these problems and to an understanding of how the mechanisms of heredity work. ●

The legacy of Mendel

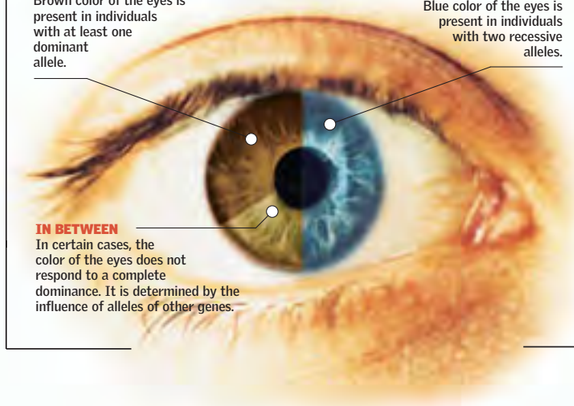
The principles proposed by Mendel are the basis of classical, or Mendelian, genetics, which reached its peak at the beginning of the 20th century. This science studies how the variants, or alleles, for a morphological trait are transmitted from one generation to the next. Later, after confirmation that the components of the nucleus are those in charge of controlling heredity, molecular genetics developed. This science studies heredity on a molecular level and analyzes how the structure of DNA and its functional units, or genes, are responsible for heredity. Molecular genetics links classical genetics and molecular biology. Its use allows us to know the relationship that exists between visible traits and the molecular hereditary information.

DOMINANT AND RECESSIVE The traits of a gene in an individual are expressed according to a pair of variants, or alleles. In general, the dominant alleles are expressed even though there may be another allele for the same gene. A recessive allele is expressed only if it is the only allele present in the pair.

DOMINANT With two dominant alleles, the individual is homozygous dominant for this trait.

HETEROZYGOUS When there is an allele of each type, the individual is heterozygous for this trait.

HOMOZYGOUS With two recessive alleles, the individual is homozygous recessive for this trait.



HOMOZYGOUS OR HETEROZYGOUS Brown color of the eyes is present in individuals with at least one dominant allele.

HOMOZYGOUS RECESSIVE Blue color of the eyes is present in individuals with two recessive alleles.

IN BETWEEN In certain cases, the color of the eyes does not respond to a complete dominance. It is determined by the influence of alleles of other genes.

FROM THE GARDEN

During the 19th century, the gardens of the Abbey of Saint Thomas were the laboratory that Mendel used for his experiments on heredity. During the 20th century, classical genetics and molecular genetics amplified our knowledge about the mechanism of heredity.

1869 The Austrian Augustinian monk Gregor Mendel proposes the laws that explain the mechanisms of heredity. His proposal is ignored by scientists.

1869 Johann Friedrich Miescher, a Swiss doctor, suggests that deoxyribonucleic acid, or DNA, is responsible for the transmission of hereditary traits.

1889 Wilhelm von Waldeyer gives the name "chromosomes" to the structures that form cellular DNA.

1900 The German Carl Erich Correns, the Austrian Erich Tschermak, and the Dutchman Hugo de Vries discover, independently, the works of Mendel.

1926 T.H. Morgan demonstrates that the genes are found united in different groups of linkages in the chromosomes.

1953 James Watson and Francis Crick propose a double-helix polymer model for the structure of DNA.

1973 Investigators produce the first genetically modified bacteria.

1977 North American scientists for the first time introduce genetic material from human cells into bacteria.

1982 The United States commercializes recombinant insulin produced by means of genetic engineering.

1990 An international public consortium initiates the project to decipher the human genome.

1997 Dolly the sheep is the first cloned mammal.

2000 The Human Genome Project and the company Celera publish the deciphered human genome.

The man who calculated

Gregor Johann Mendel was born in Heinzendorf, Austria, in 1822 and died in the city of Brünn, Austria-Hungary (now Brno, Czech Republic) in 1884. He was a monk of the Augustinian order who at the University of Vienna pursued, over three years, different studies in mathematics, physics, and natural sciences. This ample academic training and his great intellectual capacity permitted him to develop a series of experiments in which he used pea plants (*Pisum sativum*). He analyzed various traits, among them the appearance of flowers, fruits, stems, and leaves. In his methodology, he included an innovation: he submitted his results to mathematical calculations. His conclusions were key to understanding the mechanism of heredity.

PEAS The pea plants of the *Pisum sativum* species were key for the conclusions obtained by Mendel about heredity.

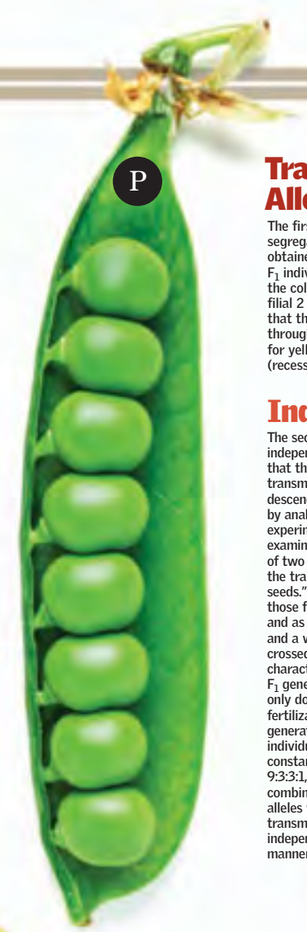
BOTANY This display is a botanical teaching tool. An altruistic naturalist, Mendel dedicated himself to conserving in herbariums the specimens of different species of plants.

Uniformity

Mendel's first law, or principle, about heredity proposes that by crossing two homozygous parents (P), dominant and recessive for the same trait, its descendant, or filial 1 (F_1), will be uniform. That is, all those F1 individuals will be identical for the homozygous dominant trait. In this example using the trait seed color, yellow is dominant and green is recessive. Thus, the F_1 generation will be yellow.

PURE INDIVIDUALS

1 Mendel used pure individuals, plants that he knew were homozygous dominant and recessive for a specific trait. For his experiments, Mendel carefully covered or directly cut the stamens of the flowers to prevent them from self-fertilizing.



CROSSING

F_1

OBTAINING THE FIRST FILIAL GENERATION

SELF-FERTILIZATION

F_2

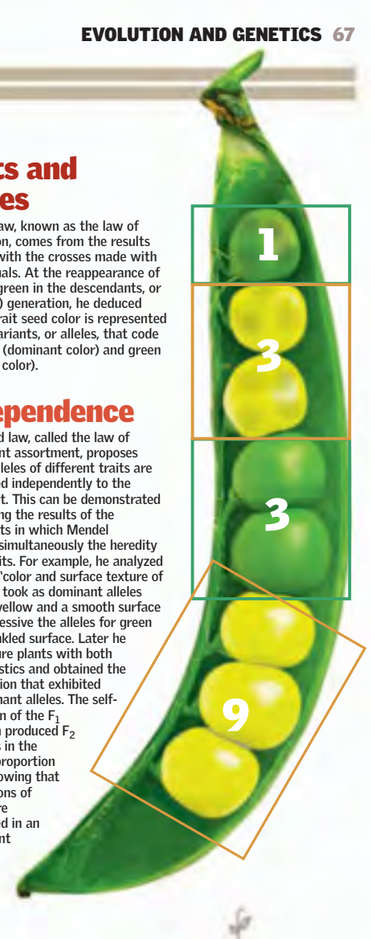
OBTAINING THE SECOND FILIAL GENERATION

Traits and Alleles

The first law, known as the law of segregation, comes from the results obtained with the crosses made with F_1 individuals. At the reappearance of the color green in the descendants, or filial 2 (F_2) generation, he deduced that the trait seed color is represented through variants, or alleles, that code for yellow (dominant color) and green (recessive color).

Independence

The second law, called the law of independent assortment, proposes that the alleles of different traits are transmitted independently to the descendant. This can be demonstrated by analyzing the results of the experiments in which Mendel examined simultaneously the heredity of two traits. For example, he analyzed the traits "color and surface texture of seeds." He took as dominant alleles those for yellow and a smooth surface and as recessive the alleles for green and a wrinkled surface. Later he crossed pure plants with both characteristics and obtained the F_1 generation that exhibited only dominant alleles. The self-fertilization of the F_1 generation produced F_2 individuals in the constant proportion 9:3:3:1, showing that combinations of alleles were transmitted in an independent manner.

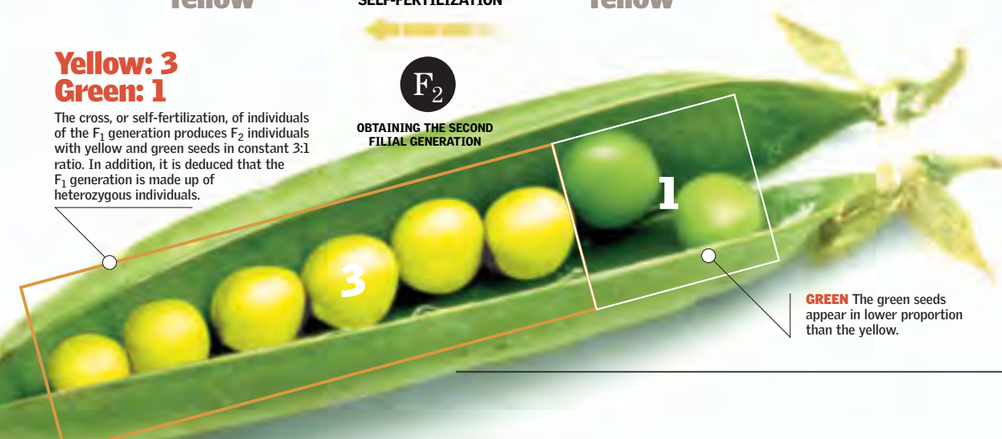


INSEMINATION

2 Once self-fertilization was impeded, Mendel inseminated the pollen of a homozygous dominant on an ovary of a homozygous recessive and vice versa. In addition to color, he analyzed other traits, such as length of stem, appearance of seeds, and color of flowers.

Yellow: 3 Green: 1

The cross, or self-fertilization, of individuals of the F_1 generation produces F_2 individuals with yellow and green seeds in constant 3:1 ratio. In addition, it is deduced that the F_1 generation is made up of heterozygous individuals.



GREEN The green seeds appear in lower proportion than the yellow.

FRUITFUL WORK

3 When the plants produced legumes, the seeds exhibited determined colors. Upon carrying out his experiments on hundreds of individuals, he obtained much information. The monk recorded the data in tables and submitted them to probability analysis. In this way Mendel synthesized his results into the conclusions that we know today as the Mendelian laws, or principles, of inheritance.

The Age of Genetics

DNA ANALYSIS
Genetic identification is a nearly infallible proof of identity used in cases of disappearance, rape, murder, and paternity suits.

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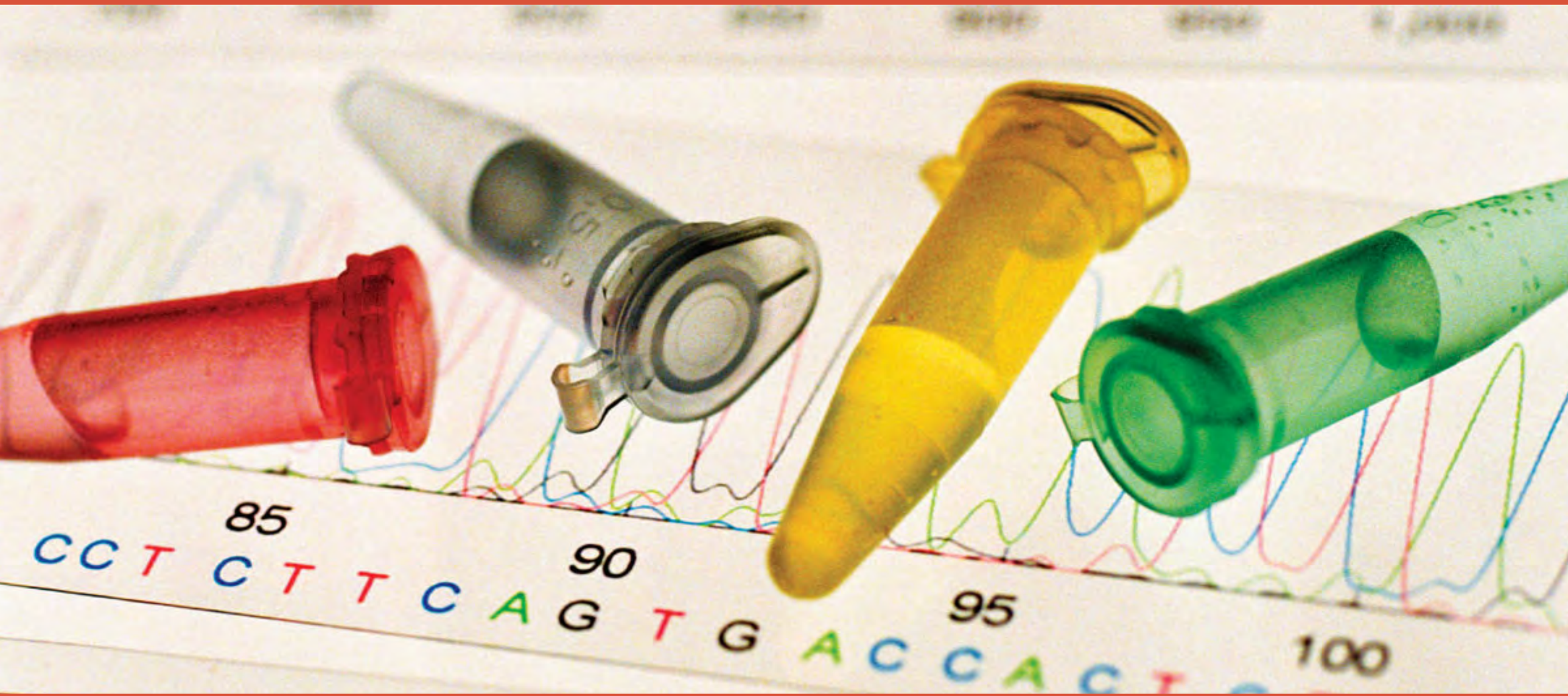


DNA analysis has become a common practice in diagnosing and predicting genetically inherited diseases. It is also highly useful in forensic procedures. The DNA sequence, like fingerprints, is unique to each individual. In these pages you will learn about achievements in the field of genetically modified foods and animals, the latest advances in genetic medicine, and future applications of stem cells. According to specialists, these cells could be used to regenerate damaged tissues or organs. Another technique that will surely provide a definitive cure for serious diseases will involve exchanging defective genes for healthy ones. ●

Genetic Solution

Genetic engineering applies technologies for manipulating and transferring DNA between separate organisms. It enables the improvement of animal and plant species, the correction of defective genes, and the production of many useful compounds. For example, some microorganisms are genetically modified to manufacture human proteins, which are vital for those who do not produce them efficiently.

Genetic Engineering

Genetic recombination consists of integrating DNA from different organisms. For example, a plasmid is used to insert a known portion of human DNA into the DNA of bacteria. The bacteria then incorporate new genetic information into their chromosomes. When their own DNA is transcribed, the new DNA is transcribed as well. Thus, the bacteria formulate both their own proteins and foreign proteins, such as human insulin.

1 Extraction

DNA is extracted from a human cell to obtain the gene that codes for producing insulin. The DNA is cut using restriction enzymes that recognize the points where the gene in question begins and ends. These enzymes also cut the bacterial plasmid. The DNA fragments thus obtained have irregular and complementary ends.

HUMAN CELL
Each body cell has genetic information distributed among the genes in the nucleus.

NUCLEUS

INSULIN GENE
The DNA sequences for producing insulin are inserted separately into different plasmids.

BACTERIAL PLASMID

2 Union

The human and bacterial DNA join at their free ends and form a recombined plasmid. This plasmid contains the human insulin gene.

RECOMBINED PLASMID WITH HUMAN DNA

ROUND CHROMOSOME

BACTERIAL PLASMID

BACTERIA
Escherichia coli contain plasmids (DNA molecules that are separate from chromosomal DNA).

MODEL ORGANISMS
Besides *E. coli*, eukaryote cells such as yeast are used.

3 Insertion

A culture of nonpathogenic receptor bacteria is placed in a solution that contains the recombined plasmid. The solution is then subjected to chemical and electrical stimuli to incorporate the plasmid that contains the insulin gene.

RECOMBINANT DNA
The recombined plasmid is inserted into the receptor bacteria.

EXTRA DNA
The plasmids may contain up to 250,000 nitrogenous bases outside the chromosome.

10 HOURS
are needed for the culture population to double.

INSERTION INTO THE CHROMOSOME
The recombined plasmid is inserted into the bacteria's chromosome.

NEW INSULIN
The transcription of human DNA enables the formation of recombined human insulin.

4 Reproduction

The bacteria reproduce constantly in fermentation tanks with water and essential nutrients. In these conditions, the recombined bacteria transcribe the information in their chromosomes to produce proteins. The bacteria also read the information from the human DNA that was inserted using the recombined plasmid, and they produce insulin.

BACTERIA
In phase of exponential growth. From now on, they will produce the hormone insulin.

5 Purification

The culture is circulated at high pressure through tiny tubes that destroy the bacteria. The solution contains a large amount of insulin that must be separated from the other proteins in the solution.

HIGH PRESSURE

TINY TUBE

CELLULAR REMAINS

INSULIN

First Case

Insulin was the first protein produced by genetic engineering. It was approved for human use in 1982.

INSULIN PROTEIN

6 Centrifugation

Centrifuges separate the various compounds present in the solution from the bacterial remains and the human insulin. The proteins present in the solid matter are separated from the original solution.

GLASS TUBES

CENTRIFUGAL FORCE
Centrifugal force accelerates the decantation.

DECANTATION
The centrifuges reduce the amount of time necessary to separate the solid matter.

BEFORE CENTRIFUGATION

Insulin in bacterial batch

AFTER CENTRIFUGATION

The separated material that contains bacterial remains.

Insulin pellet

7 Formulation

The recombinant human insulin is chemically modified. This produces a stable, aseptic compound that can be administered therapeutically via injection.

recombinant antibiotics and vaccines

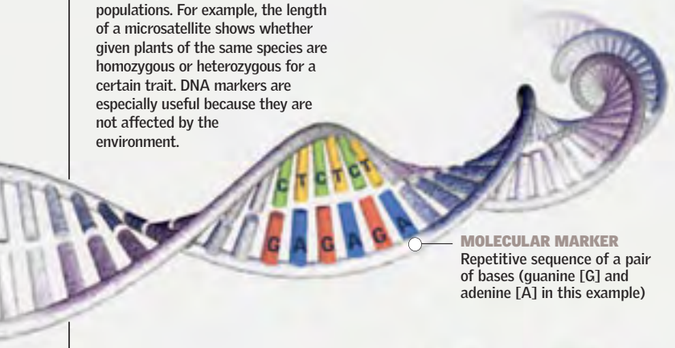
ARE ALSO PRODUCED BY GENETIC ENGINEERING.

DNA Markers

In the past, individual plants in agriculture were chosen for reproduction according to visible characteristics or markers, such as the shape and color of fruit. Genetics demonstrated that these characteristics come from the expression of genes. The genes can also be accompanied by repeating groups of bases called DNA markers. These markers are useful primarily during the early phases of a plant's development to detect whether it has a certain trait.

Microsatellites

DNA has different types of molecular markers. Some of the most useful markers are called microsatellites. These markers are groups of up to 10 DNA bases that are repeated in short sequences. Microsatellites are very useful in evaluating plant and animal populations. For example, the length of a microsatellite shows whether given plants of the same species are homozygous or heterozygous for a certain trait. DNA markers are especially useful because they are not affected by the environment.



MOLECULAR MARKER
Repetitive sequence of a pair of bases (guanine [G] and adenine [A] in this example)

1 Extraction

Molecular markers are extracted from DNA taken from a tissue sample. In the case of plants, even a tiny leaf may give enough DNA.

2 Preparation

Restriction enzymes are used to snip portions of DNA that have the microsatellite. After the microsatellite is isolated, it is multiplied into thousands of identical units using a process called polymerase chain reaction (PCR). This process is carried out with each of the samples obtained from different individuals to be compared. For example, comparing microsatellites from different tomato plants can show which individuals are heterozygotic or homozygotic or recessive or dominant for specific traits.

SAMPLE 1 | **SAMPLE 2** | **SAMPLE 3**

GA GA GA
GA GA GA
Microsatellite of a dominant homozygote.

GA GA GA
GA GA
Microsatellite of a heterozygotic individual

GA GA
GA GA
Microsatellite of a recessive homozygote

MICROPIPETTE
This instrument is used to insert an exact amount of the DNA sample.

DNA SAMPLE
Samples containing microsatellites and a substance that glows in UV light are scattered in a pocket of polyacrylamide gel.

NUMBER OF SAMPLES
More than 50 DNA samples can be placed for comparison in the same gel.

3 Electrophoresis

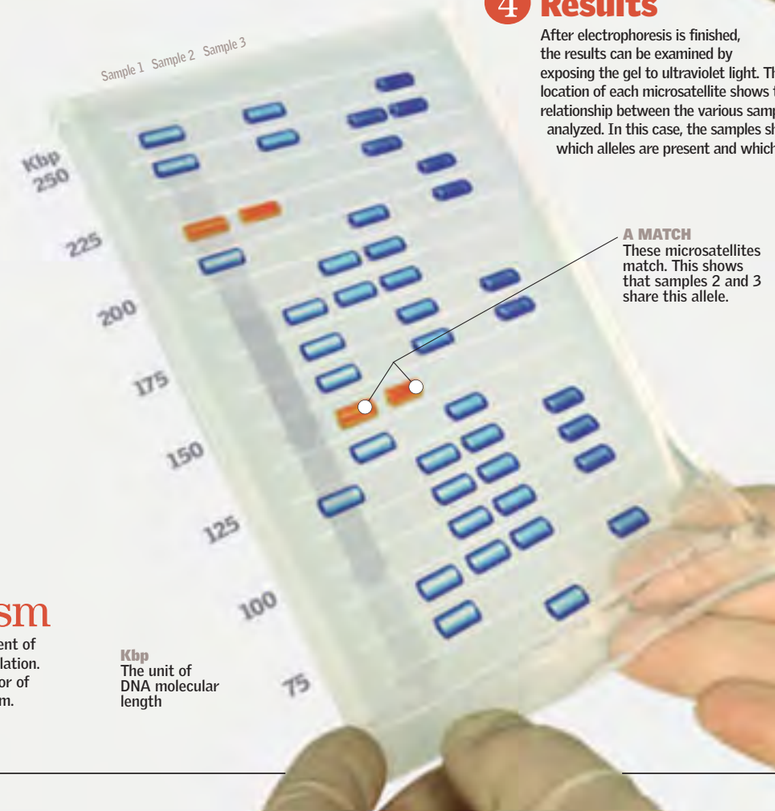
Once the microsatellite samples are placed in the polyacrylamide gel, the gel is subjected to electrophoresis. This technique is widely used to separate molecules, in this case microsatellites, with a negative electrical charge by applying a current of electrons. When an electrical field is generated, electricity moves the microsatellites through the gel at different speeds. Their movement varies with the ratio of the electrical charge to the mass of each microsatellite. The lighter microsatellites travel farther than the longer ones.

POLYACRYLAMIDE GEL

ELECTRIC CURRENT
The positive electrical charge attracts the negative charges in the gel.

4 Results

After electrophoresis is finished, the results can be examined by exposing the gel to ultraviolet light. The location of each microsatellite shows the relationship between the various samples analyzed. In this case, the samples show which alleles are present and which are not.

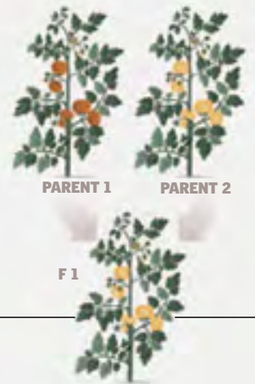


A MATCH
These microsatellites match. This shows that samples 2 and 3 share this allele.

Kbp
The unit of DNA molecular length

Based on Mendel

The Mendelian laws, essential to the development of the field of genetics, were discovered based on the markers of visible traits. These traits are very useful, except for a few disadvantages: they are based on an individual's phenotype (appearance), which is influenced by the environment. In addition, it is necessary to wait until a specimen is fully grown in order to find out whether it has a desired trait.



YELLOW LARGE
The dominant allele is expressed.

RED SMALL
This new trait may be of interest in a new crop.

RED LARGE
The recessive allele is expressed.

Polymorphism

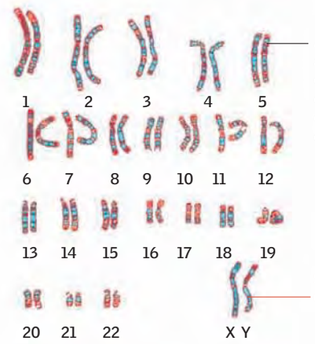
Variations in the sequence of a segment of DNA among the individuals of a population. For example, the variations in the color of tomatoes are a result of polymorphism.

Genome in Sight!

One of the most far-reaching and extraordinary scientific achievements is the deciphering of the human genome. This is the complete set of hereditary information contained in the DNA of human chromosomes. In less than 20 years, with a combination of original genetic techniques and the power of computers, scientists glimpsed the location of all the genes, including those that determine eye color, hair type, blood type, and even a person's sex. ●

Genetic dictionary

The 46 human chromosomes, together with mitochondrial DNA, contain all a human being's genetic information. Knowing the location and function of each gene or group of genes is useful for several reasons. It enables us to know if an illness stems from a defect in a gene or group of genes and even to correct the illness through gene therapy. We can also better understand any potential interaction among genes that are near each other in a chromosome and the effects of that interaction. Studying the human genome can even reveal the origin of our species among the primates.



AUTOSOMES are the 22 pairs of human chromosomes, excluding the sex chromosomes.

SEX CHROMOSOMES

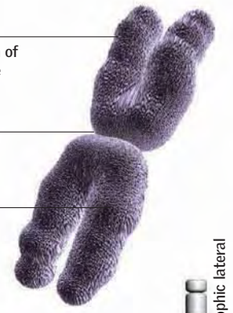
WOMEN have a pair of the same sex chromosome, called XX.

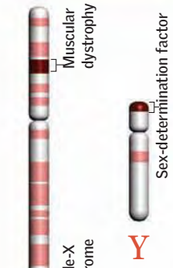
MEN have a chromosome pair made up of two different chromosomes, X and Y.

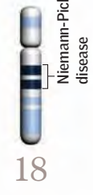
PLANT
25,000
genes

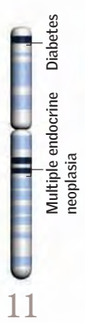
Chromosome

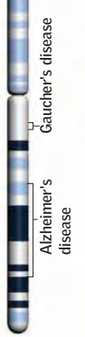
contains tightly coiled and folded DNA. It consists of sister chromatids that contain the same genes.





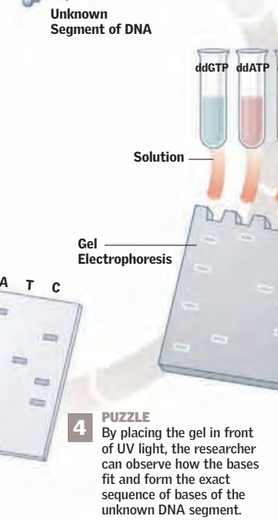






Sanger Method

Frederick Sanger, an English biochemist, devised an extraordinary method for deciphering the human genome by identifying the location of each nitrogenous base in the DNA. He divided human DNA into portions of different sizes and used the PCR technique to make thousands of copies. He then made in vitro copies of each DNA fragment using the cellular mechanism of DNA replication. He added his own twist to this process by using fluorescent dideoxynucleotides (ddNTP). These molecules compete with standard nucleotides during the DNA replication process.

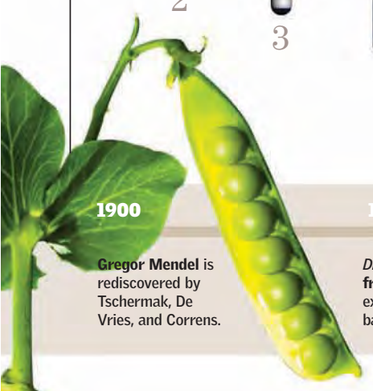


1 MULTIPLICATION
Each segment of DNA in which the sequence of bases is unknown is subjected to the polymerase chain reaction (PCR), which makes it possible to make thousands of copies of the same segment of DNA.

2 IN VITRO
Solutions with high concentration of a ddNTP, for example ddGTP, will produce copies of DNA of different length from standard nucleotides. It works because the DNA-copying process is interrupted if a ddNTP is inserted instead of a standard nucleotide.

3 ELETROPHORESIS
On a gel, the copies of DNA travel different distances according to their length. This movement is called electrophoresis.

4 PUZZLE
By placing the gel in front of UV light, the researcher can observe how the bases fit and form the exact sequence of bases of the unknown DNA segment.



1900 **Gregor Mendel** is rediscovered by Tschermak, De Vries, and Correns.

1911 *Drosophila melanogaster,* **the fruit fly,** is the subject of experiments by T.H. Morgan based on chromosomal theory.

1953 James Watson and Francis Crick propose a structural model of DNA.

1955 Discovery that the human species has **46 chromosomes**

1968 The first description of a **restriction enzyme**

1974 John Gurdon first used somatic nuclei to create **clones** of an amphibian larva.

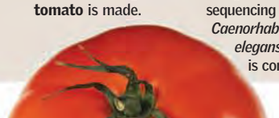
1975 F. Sanger develops a technique for deciphering the sequence of bases in DNA.

1981 The first transgenic **rats** and **insects** are obtained.

1983 Kary Mullis creates the **polymerase chain reaction technique.**

1993 A plan is proposed to finish **sequencing** DNA in the human genome project.

1994 The first **transgenic tomato** is made.



1998 The genome sequencing of the *Caenorhabditis elegans* nematode is completed.

2003 The magazines *Science* and *Nature* publish **the complete sequence of the human genome.**

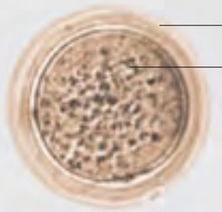
Stem Cells

The reasoning is simple: if an organism with more than 200 different types of cells is formed from a group of embryonic cells without specialization, then manipulating the division of these original cells (called stem cells) should make it possible to generate all the human tissues and even produce autotransplants with minimal risk. Although such work is in progress, the results are far from being a medical reality. Scientists all over the world are studying its application. ●

EMBRYONIC CELLS
This photograph shows the eye of a needle with an embryo formed only by stem cells before cellular differentiation begins.

Cellular Division

All the cells of higher organisms divide and multiply through mitosis, with the exception of the reproductive gametes. Mitosis is the process through which a cell divides to form two identical cells. For this to happen, the first cell copies its genetic material inside the nucleus, and later it slowly partitions until it fully divides, producing two cells with the same genetic material. An adult cell divides on average 20 times before dying; a stem cell does it indefinitely.



CYTOPLASM

NUCLEUS
contains the DNA. First it duplicates the DNA, and then it divides.

1 Obtaining

Because the stem cells are the first that form after fertilization occurs, they are abundant in the placenta and especially in the umbilical cord. Geneticists obtain them from the cord once the baby has been born, and it is possible to freeze the cord to harvest the stem cells later.

UMBILICAL CORD
There are many stem cells because they are not differentiated.

STEM CELL

2 Multiplication

Once isolated, stem cells are cultivated in vitro under special conditions. It is common to resort to a substrate of irradiated cells, which serve as support without competing for space. Later, every seven days, they need to be separated to keep them from dying and to be able to reproduce them.

16 cells

IS THE LIMIT FOR CULTIVATION. THIS LIMITATION GUARANTEES THE ABSENCE OF A HUMAN EMBRYO. THE EXACT NUMBER IS DEBATED.

MITOSIS
The cells multiply according to their genetic program.

STEM CELLS

STEM CELLS
divide indefinitely without losing their properties.

3 Differentiation

The stem cells are pluripotent, which is to say that they have the power to create any of the more than 200 different cells of the body. This process happens as the embryo grows. If the optimal conditions could be created in vitro, it would be possible to form in a laboratory all the cells of the body using the genetic program of the cells. In practice, this technique is possible only with a few types of cells, in particular blood cells.

ACTIVATORS
Chemical and hormonal activators guide the specialization.

NEURONS
have yet to be grown in the laboratory.

THERE ARE MORE THAN **200** TYPES OF CELLS IN THE HUMAN BODY

WHITE BLOOD CELL
Some tests have managed to produce them.

RED BLOOD CELL
Generating them in vitro has been achieved.

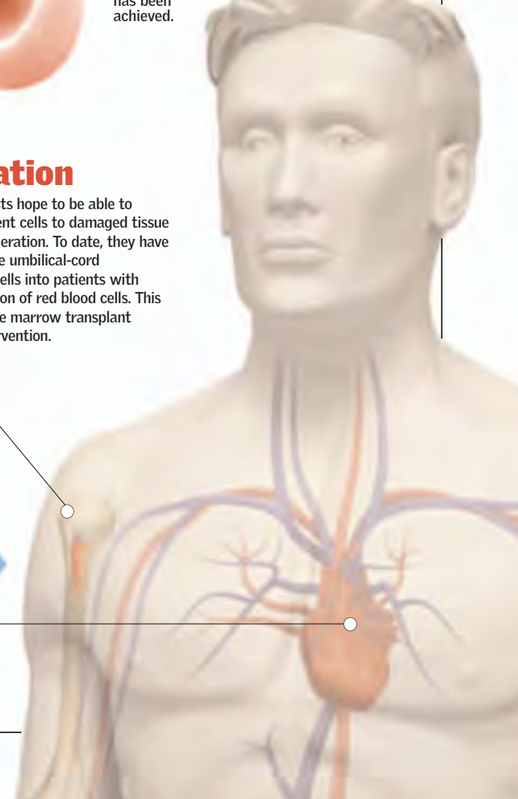
FIRST USE
In 1998 stem cells were isolated and cultivated for the first time in the United States. Since then, numerous laboratories in the world have cultivated them. Because of ethical questions that surround work with embryonic cells, each line is monitored through official organizations.

4 Implantation

Doctors and geneticists hope to be able to provide new pluripotent cells to damaged tissue and provoke its regeneration. To date, they have been able to introduce umbilical-cord hematopoietic stem cells into patients with dysfunctional formation of red blood cells. This is equivalent to a bone marrow transplant without surgical intervention.

BLOOD
Reproduced in vitro, the stem cells are then injected.

HEART
Stem cells are being used to repair the heart after an infarction.



Cow Cloning

The term "cloning" itself provokes controversy. Strictly speaking, to clone is to obtain an identical organism from another through technology. The most commonly used technique is called somatic-cell nuclear transfer. It was used to create Dolly the sheep as well as other cloned animals, including these Jersey cows. The technique consists of replacing the nucleus of an ovule with the nucleus of a cell from a donor specimen. When the ovule then undergoes division, it gives rise to an organism identical to the donor. With all such processes, there exist slight differences between the donor and the clone. In only one case is the clone perfect, and it comes naturally: monozygous (identical) twins. ●

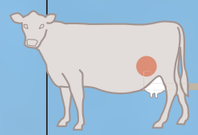
1 Obtaining the Nucleus

A specialized cell of an adult animal, whose DNA is complete, is isolated, and it is cultivated in vitro to multiply it. Various ovules of a donor cow are also isolated. The nucleus is then removed from both groups of cells—only those of adult cells.

NUCLEUS EXTRACTION
A fibroblast is extracted from the ear of an exemplary adult.

Nucleus with **Complete DNA (60 chromosomes)**

Ovule Without Nucleus



OVULE EXTRACTION
An ovule is obtained from the ovary of another exemplary specimen, and the nucleus is removed.

PIPETTE
supports the ovule and prevents it from shifting in the operation.

2 Nucleus Transfer

Consists of replacing the nucleus of the ovule with that obtained from the adult cell. In this form, the chromosomes carried by the new nucleus complete the ovule in the same way as if the ovule had been fertilized by a spermatozoon. Once fused, the cell will begin its program of division as if it were a zygote (fertilized ovule).

NUCLEUS OF THE CELL TO CLONE
The nucleus is transferred to the ovule.

OVULE WITHOUT NUCLEUS
Only the cytoplasm, with organelles like mitochondria, remains.

DIVERSE USES
Cloning can be applied for obtaining new organisms and tissues and for reproducing segments of DNA.

PIPETTE
It is used to introduce the nucleus into the ovule.

3 Fusion

By means of light electric discharges, fusion of the donated nucleus with the cytoplasm of the ovule is initiated. Three hours later, calcium is added to the cell to simulate fertilization. An interchange begins between the nucleus and the cytoplasm, and the cell starts to divide.

2 cells

8 cells

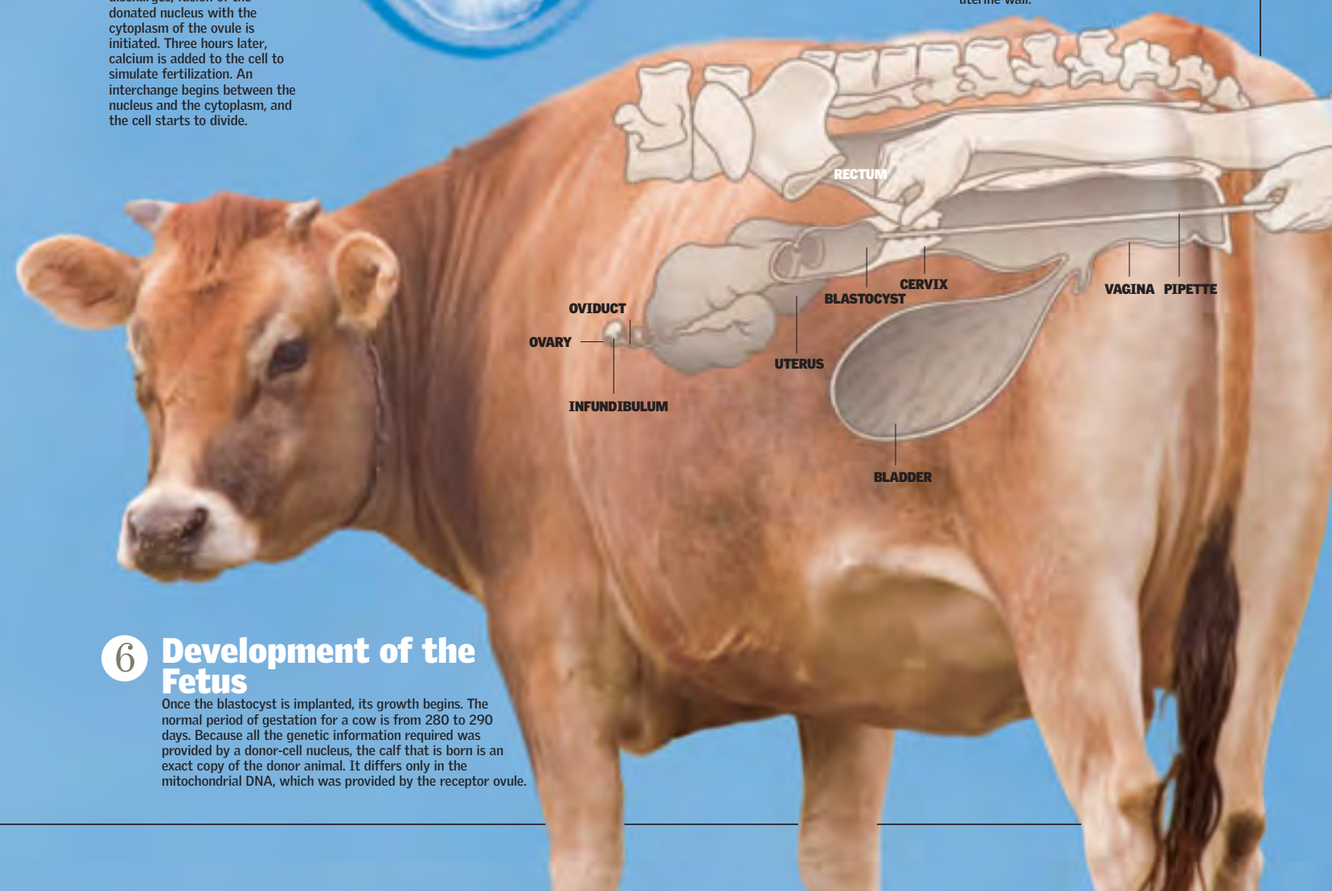
16 cells

4 Cultivation

The new cell is cultivated in vitro, where it multiplies until forming a blastocyst (cellular group whose cells are not yet differentiated by function and is a precursor to an embryo). The developing blastocyst is maintained in a medium that contains hormones and 5 percent oxygen to simulate the conditions of a cow's uterus. After a week, the developing mass has become large enough that it can be implanted into the actual uterus of a cow.

5 Insemination

The blastocyst is implanted in the uterus of a donor cow on the sixth day after the cow has stopped being in heat so that the development of the blastocyst continues in a natural way. If everything goes as planned, the blastocyst adheres to the uterine wall.



Cost

The technology is still not efficient. For this Jersey, 934 ovules were transferred, of which 166 fused, and only one developed successfully.

6 Development of the Fetus

Once the blastocyst is implanted, its growth begins. The normal period of gestation for a cow is from 280 to 290 days. Because all the genetic information required was provided by a donor-cell nucleus, the calf that is born is an exact copy of the donor animal. It differs only in the mitochondrial DNA, which was provided by the receptor ovule.

Biochip Applications

Devices that use a small, flat substrate (chip) that contains biological (bio) material are commonly called biochips. Biochips are used for obtaining genetic information. A biochip is a type of miniaturized equipment that integrates tens of thousands of probes made up of genetic material having a known sequence. When the probes are placed in contact with a biological sample (such as from a patient or experiment), only the nucleotide chains complementary to those of the chip hybridize. This action produces a characteristic pattern light, which is read with a scanner and interpreted by a computer.

SMALL SIZE
Biochips are the size of a stamp and are contained in a glass structure.

0.2 inch (4.5 mm)

0.3 inch (6.4 mm)

MASK
Template with microarray of cells

PHOTODEGRADABLE FILM
functions as an intermediary layer.

GLASS SUBSTRATE
is chemically treated with certain reactive groups to permit the implantation of the oligonucleotides.

1 Procedure

This biochip has a template, or pattern—called a genetic microarray—that makes it possible to compare the DNA of one tissue sample from a person with the genes that cause a disease. In the case of a particular type of cancer, for example, researchers want to know the genes that are involved in the disease.

NORMAL
The cDNA (complimentary DNA) of normal cells is colored with a green fluorescent marking.

Cells of Normal Tissue

Cells of Cancerous Tissue

CANCER
The cDNA of cancerous cells is colored with a red fluorescent marking.

MIX
The tubes of green and red markings are combined in the same tube.

COMPUTER
The pattern is input into a special computer where the microinjectors will take care of filling the 96 orifices, or spots, on the biochip.

2 Samples

A microinjector fills each one of the pores in the biochip with samples of the different sequences of genes from the organism.

3 Microinjection

Through microinjection, each spot is filled with cDNA marker of both fluorescent substances (coming from cancerous and normal tissues combined).

COLOR FILTER

LIGHT RAYS

Spots filled with cDNA marked with both fluorescent substances

4 How It Works

Once the injection of the marking mix is finished, it is necessary to detect which stuck to what spot. For this, the array is placed in a scanner with a green and a red laser, which excite the fluorescent targets. The microscope and the camera work in conjunction to create an image, and this information is stored in a computer.

5 Results

All the points of the marked biochip have small sequences of DNA that are compared with a sequence of the samples. The fluorescent signals, detected by means of a computer, indicate which of the DNA sequences on the chip have complementary sequences in the sample. A special program is used to calculate the proportion of red to green fluorescent signals in the image.

GREEN
The gene found in this spot expresses normal conditions.

RED
The gene found in this spot expresses cancerous conditions.

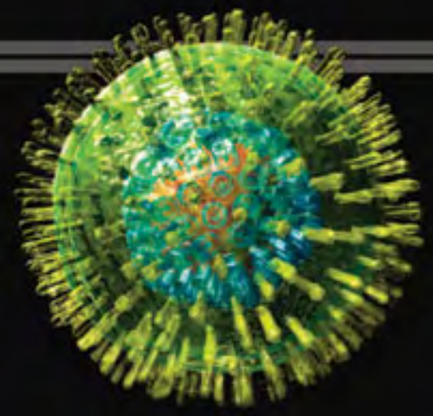
YELLOW
The gene found in this spot expresses normal conditions together with those of cancer.

Gene Therapy

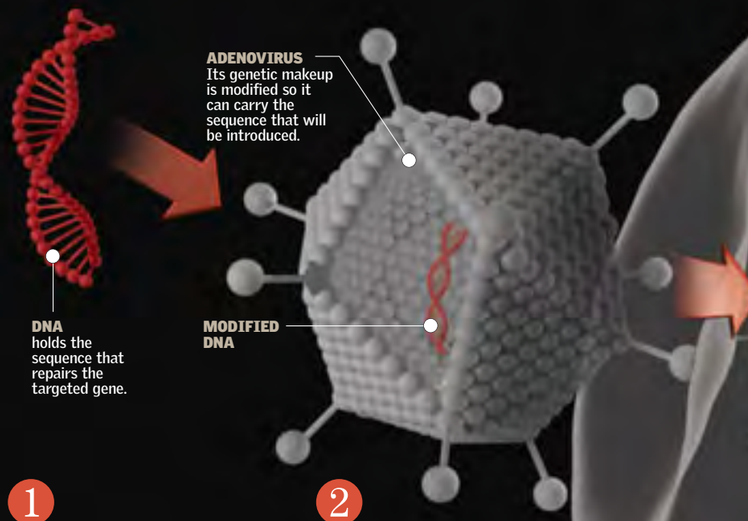
One of the latest breakthroughs in medicine, gene therapy is used to introduce genetic material to correct deficiencies of one or more defective genes that are the cause of an illness. Several different techniques have been developed for use with human patients, almost all of which are at the research stage. The problem with illnesses with a genetic origin is that therapy must modify the cells of the affected organ. To reach all these cells, or a significant number of them, demands elaborate protocols or, as is the case for viruses, the use of nature's biological weapons to cause other illnesses.

Treatable Illnesses

Illnesses with a genetic origin are difficult to treat, since the organism has poorly coded genes and the fault is therefore present in all its cells. Cystic fibrosis and Duchenne muscular dystrophy are examples of monogenetic illnesses that can potentially be treated with these therapies. Gene therapy has also been attempted on cancer and HIV infection, among other pathologies. A definitive cure may be found for many genetic illnesses, but the techniques for gene therapy are still in the development stage.



HERPESVIRUS
The herpesvirus is an icosahedral virus and holds a DNA sequence that needs to be modified so that it will not cause an illness. It is widely used in gene therapy.



1 Identification

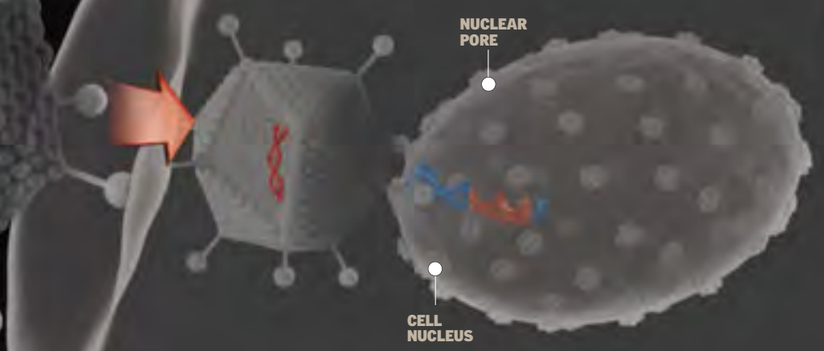
The DNA sequence that corresponds to the gene that causes the deficiency requiring treatment is identified. Then the correct sequence is isolated and multiplied to guarantee a quantity that can modify the organism. Because a monogenetic illness generally affects the function of one organ, the cell volume that is targeted for modification is large. Then a technique is chosen to transfect the cells.

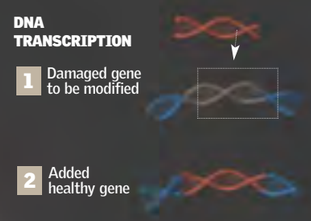
2 Vehicle

An adenovirus is an icosahedral virus that contains double-stranded DNA and lacks an outer envelope. It is primarily the cause of a number of mild respiratory illnesses. If the virus can be modified to be nonpathogenic, it has the potential for use in transporting a modified sequence of DNA in a region called a cassette. Even though its capacity is limited, its effectiveness rate is very high.

3 Replacement

The modified adenovirus is inoculated in a cell culture to generate the viral infection. It then enters the cells and multiplies in the cytoplasm, copying its DNA, including the modification carried in the cassette, in the nucleus of the infected cell, where it transcribes the new information.



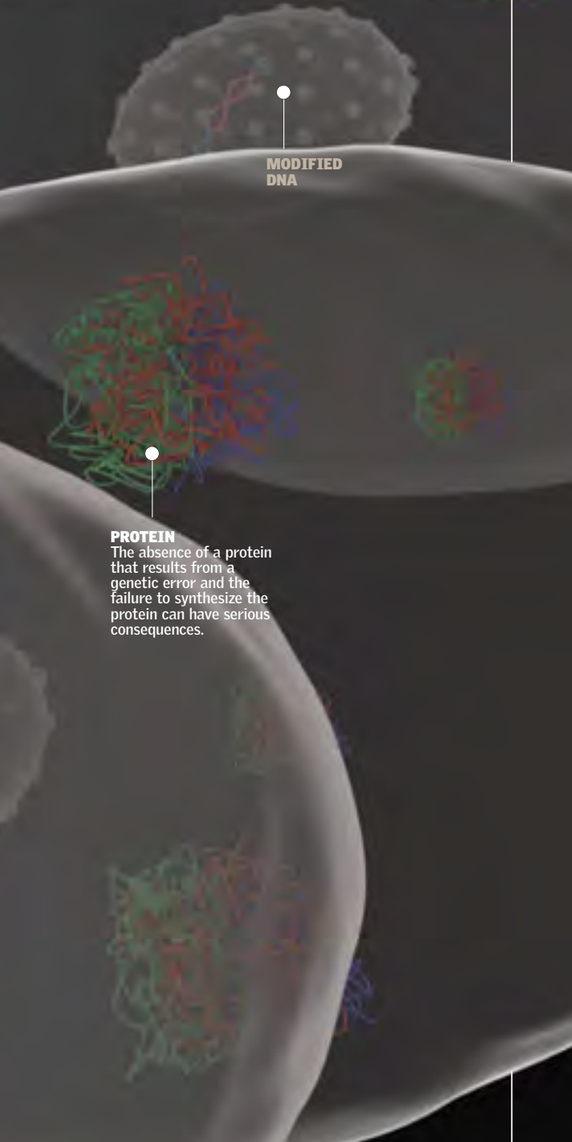


4 Synthesis

The infected culture cells, which have the new genetic information, can now synthesize the compound that caused the dysfunction. Generally these are proteins that cannot be synthesized because the gene for their elaboration is disassociated or damaged. The process begins once the cells divide and transcribe the gene in question. The protein that was not synthesized before is now transcribed and produced.

Relationship

It is critical that the hypothetical number of cells to be modified and the number of viruses needed for the therapy to work are in the correct relationship.



Kilobase

The unit in which DNA and RNA are measured; the capacity of a virus's cassette, which on average is approximately five kilobases.

NONVIRAL GENE THERAPIES
Many are based on physical means such as electrical techniques. They have the advantage of producing material in vitro, which allows for a large transfer capacity not limited by the number of bases that can be transfected by a virus. The problem is that these methods are not efficient for reaching target cells in the organism. The most important therapies of this type are microinjection, calcium phosphate precipitation, and electroporation (the use of an electric field to increase the permeability of the cell membrane).

DNA Footprints

Since Sir Alec Jeffreys developed the concept of the DNA profile for the identification of people, this type of forensic technique has taken on significant importance. A practically unmistakable genetic footprint can be established that allows for the correlation of evidence found at the scene of a crime (hair, semen, blood samples) with a suspect. In addition, the use of this technique is a key element to determine the genetic link in kin relationships.

SWAB
For saliva samples. Then it is immersed in a solvent solution and the DNA extracted.

1 Sample Collection

Any body fluid, such as urine, blood, semen, sweat, and saliva, or fragments, such as tissues, cells, or hairs, can be analyzed to obtain a person's DNA. There is generally always something left at the scene that can be used as a sample.

Each sample is placed in separate plastic bags, sealed, and certified to avoid adulterations.

Only a very small amount of evidence is needed for sampling. For example, just a small fraction of a drop of blood or sperm is sufficient.

FACTORS THAT ALTER DNA

Moisture or water will denaturalize a sample faster.

Heat is one of the most destructive factors.

2 DNA Separation

HAIR FOLLICLE
A follicle has DNA that is easy to obtain.

TWEEZERS
must be properly sterilized.

LABELING
is absolutely necessary so that the samples are not mixed up.

1 HAIR DIGESTION
The hair is divided into sections. These are then put into a tube, and solvents are applied.

2 CENTRIFUGING
The suspended DNA must be centrifuged to separate it from the rest of the cell material.

MICROPIPETTE
Only the substance floating on the surface is extracted. This is where the DNA is.

3 PRECIPITATION
A 95 percent solution of ethanol is added; the sample is shaken and then centrifuged at a higher speed than before.

Surface-floating substance and pellet

DISPOSABLE MATERIAL
All the material that is used must be disposable to avoid contaminating the DNA.

4 SURFACE-FLOATING SUBSTANCE
A 70 percent solution of ethanol is added, and the mixture is rinsed with water. The DNA is free of impurities and ready for analysis.

DNA and pellet of leftover materials

3 DNA Magnification

The polymerase chain reaction (PCR) is carried out by a machine that, using heat, synthetic short nucleotide sequences, and enzymes, copies each fragment of DNA as many times as needed. This amplification makes it possible to conduct a large number of tests while conserving the DNA. Later the DNA fragments are separated by means of capillary electrophoresis.

Visualization of the DNA as curves on the monitor

4 Impression and Comparison

The machine presents the results as curves, where each base has a specific location according to the height of the curve in the graph sequence. It then compares the sample obtained at the crime scene with those obtained from the crime suspects. If one of them was at the scene of the crime, the curves coincide exactly in at least 13 known positions.

DNA-EVIDENCE GRAPH

The numbers represent a position in the DNA sequence.

100 105 110

CYTOSINE GUANINE THIAMINE ADENINE

DNA GRAPH FOR SUSPECT A

COINCIDENCE OF GENETIC PATTERNS

DNA GRAPH FOR SUSPECT B

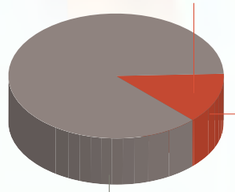
13 locations

is the minimum number of coinciding points that need to be found for a suspect to be accused of a crime in the United States.

Power of Exclusion (PE)

Overall, for a DNA test to be considered as valid criminal evidence, at least in theory, it should be able to guarantee a PE with a certainty above 99.9999999 percent. The PE is measured as a percentage but is expressed as the number of people who are excluded as possible bearers of the DNA at the crime scene. Thus, a sample is taken at random from one person, as a type of witness, and it is then compared with the DNA from the evidence and that of the suspect. The detail of the analysis must be so precise that it can, at least theoretically, be able to discriminate one person among one billion people. In practice, the test is valid if it statistically discriminates one person in one billion. All this is done to guarantee the results of the test and so that it can have validity in court. In practice, the suspects are not chosen randomly but fulfill other evidence patterns, among which DNA is used to confirm these patterns.

1 in 1,000,000,000
is the STATISTICAL GUARANTEE.



6,500,000,000
is the WORLD'S POPULATION.

GUARANTEED POWER OF EXCLUSION

Filial DNA	1:100 million
Forensic DNA	1:1 billion

Modified Foods

Genetically modified foods have always existed. An example is wine, modified through the fermentation of grapes. However, modern biotechnology based on DNA decoding has made these processes predictable and controllable. The process improves specific characteristics of the plant, makes it more resistant to pests, and improves its nutritional quality. The objective is a greater production of food with better agronomic and nutritional characteristics. ●

More benefits

The development of transgenic plants has allowed the production of food with more vitamins, minerals, and proteins, or with less fat. The development of genetic technology has also been able to delay the maturation of fruits and vegetables and, in other cases, make them more resistant to specific pests, thus reducing the need for applying insecticides to crops. The genetic modification of some crops also produces smaller and stronger plants, while simultaneously increasing their yield, because they invest more energy into producing their edible parts.

The marine strawberry

Research has been conducted in modifying strawberries with a gene from the plaice to make the fruit more resistant to frost. This is a simple process from which the crop yields can be improved by a high percentage.

1 The gene that keeps the plaice from freezing is copied and spliced into a plasmid taken from a bacterium.

Bacteria DNA

Antifreezing gene

2 The plasmid from the bacterium that holds the plaice gene is then inserted onto a second bacterium.

Second bacterium

3 A strawberry cell culture is infected with the antifreezing gene. This is then integrated into the strawberry DNA, and plant transgenesis takes place.

Strawberry cell

Antifreezing gene

4 The new transgenic strawberry can reproduce as many times as it wants.

Bacteria

Recombinant plasmids

Test tube

CONJUGATIVE PLASMIDS
The plasmids are mixed with DNA bits to form conjugative plasmids.

ELECTRICAL PULSES
Bacteria are added, and quick electrical pulses are applied that cause the plasmids with the transgene to enter the bacteria.

RESTRICTION ENZYME
The enzyme is added to the cloned DNA in a test tube to segment or divide it into pieces the size of the gene. The bacterial plasmids that were extracted using the same enzyme are added in another test tube.

1 Cloning the Desired Gene

All the DNA is extracted from the *Bacillus thuringiensis* bacteria in order to locate and copy the gene responsible for this characteristic.

bacterium *Bacillus thuringiensis*

DNA

Desired Gene

BT Corn

has been genetically modified to make it resistant to the western corn rootworm, a pest that feeds on the root of the plant. Bt corn produces the Bt toxin, a toxin naturally produced by a soil bacterium. The pest is killed either when the larvae attempt to feed on the root or the adults attempt to feed on the foliage of the Bt corn.

Endogenous Bacterial Plasmid

Plasmid with Insect Toxin Transgene

TRANSGENIC BACTERIA
Recombinant plasmids enter the bacteria that will express the genes.

DESIRED GENE
Bacteria multiply to obtain a copy of each one of the thousands of genes from the organism. The desired gene is located and hundreds of copies are made.

Petri Dish

2 Modified Gene Design

The gene is composed of a codified sequence (wanted gene) and of regulatory sequences, which can be altered for the gene to be expressed in a desired form. The selected gene confers an advantage, for instance, resistance to an herbicide.

P WANTED GENE T P SELECTED GENE T

3 Transformation

The modified gene is inserted into the nucleus of the corn cell so that it can be incorporated into some of the chromosomes. For this effect, the gene pistol, or gene cannon, is used.

Gold Particle

Hundreds of gold particles are covered or plated with thousands of copies of the new gene.

The gold particles are shot toward the cell sample.

Corn Cell Culture

If the particle enters the nucleus, the genes are dissolved and can be incorporated into the chromosomes' DNA.

Chromosome

Nucleus

4 Culture

The transgenic corn cells are distributed in crop media that contain the necessary nutrients. Those that proliferate form a whole plant from transformed cells. The adult transgenic plants are transplanted to the agricultural fields. This transgenic corn and its descendants will be resistant to the western corn rootworm.

The labels

Transgenic foods have their own label. This is a legal requirement in most countries. When the time comes to shop for fruits, vegetables, or cereals at the supermarket, we must look closely at the labels. In the case of corn or rice, only 9 percent should be transgenic. This should be clearly explained in the list of ingredients.

Golden rice

Golden rice is the first organism that was modified genetically for the purpose of providing an increased level of vitamin A for populations with a deficiency in the vitamin. The embryo of golden rice stores beta carotene and other carotenes, which are the precursors of vitamin A.

1 The genes used are those that encode for the enzymes phytoene synthase and lycopene synthase in the plant *Narcissus pseudonarcissus* and the enzyme carotene desaturase from *Erwinia uredovona* bacteria.

Narcissus pseudonarcissus

Erwinia uredovona

2 The DNA strands from these genes are inserted into plasmids, which are later introduced into *Agrobacterium tumefaciens* bacteria.

Plasmids

3 Agrobacteria are inoculated into immature rice crop embryos.

Agrobacteria

4 Transgenic plants are obtained from these crop embryos, which generate transgenic rice grains with extra vitamin A in its endosperm.

Endosperm where vitamin A accumulates

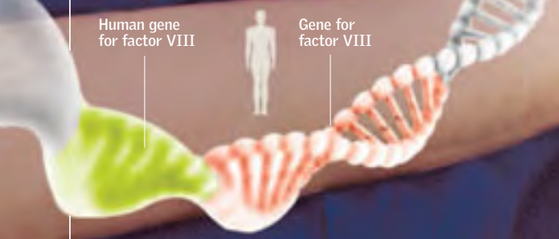
Pharmaceutical Farms

A transgenic animal is one in which foreign genes have been introduced through genetic engineering, integrated into the animal's genome, and transmitted from generation to generation. The first achievements in this field were made with cell cultures, and the first "whole" animal that was obtained with an exogenous gene was a rat. Other mammals, such as rabbits, pigs, cows, sheep, goats, and monkeys, are being genetically manipulated for medical or animal-production purposes.

TRANSGENIC PIGS
Investigators at the Pharmaceutical Engineering Institute of Virginia Tech hold three of the specimens.

Pigs to cure hemophilia

Scientists at the Pharmaceutical Engineering Institute of Virginia Tech and colleagues added the gene for the factor VIII protein of human coagulation to a few transgenic pigs. This protein is of vital therapeutic importance as a coagulant agent for type A hemophiliacs.



1 **FACTOR VIII** is identified and the gene copied. A procedure is then worked out to cause this gene to be expressed only in the mammary gland of the pigs so that the factor is produced in their milk.

Low Cost

The proteins of factor VIII and factor IX that are injected into patients with hemophilia come from human blood plasma and are very costly. In contrast, in the future, an injection of such proteins purified from the milk of transgenic livestock could cost only a dollar per injection.

2 **ANIMAL TRANSGENESIS** is accomplished with the microinjection of the human gene of factor VIII directly into fertilized ovules, so that the sequence integrates into its genome.

3 **IMPLANT** The ovule is implanted in the uterus of an adoptive mother, which has been hormonally prepared.

4 **BIRTH** Once the female transgenic pigs are born, it is necessary to verify that they have at least one copy of the transgene.

5 **MILK WITH FACTOR VIII** When adulthood is reached, the female pig produces milk with factor VIII, which can help those sick with hemophilia.

6 **FACTOR VIII** is extracted from the milk. The protein is purified and the desired pharmacological product obtained.

Hypoallergenic Cats

Cat lovers who have not been able to fulfill their dreams of having a cat as a pet because of their allergies are giving a hint of a hopeful smile. A U.S. company had planned to genetically engineer cats to produce a very low level of a saliva protein that causes allergic reactions in humans but later chose to use selective breeding.

Spiders with threads of steel

Recombinant spider silk, called BioSteel, has been produced from the milk of goats implanted with the gene of the spider *Nephila clavipes*, commonly known as the golden thread spider. Similar to natural spider silk, the product was reported to be five times stronger but lighter than steel, silky in texture, and biodegradable.

Fluorescent rats

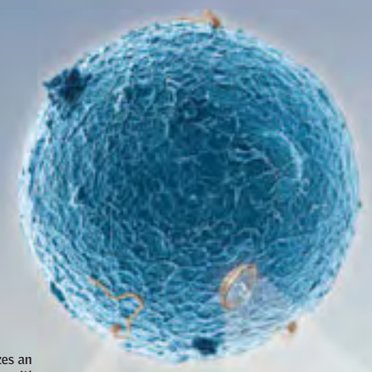
The Research Institute for Microbial Diseases at Osaka University, Japan, obtained the FGP (fluorescent green protein) gene of the jellyfish *Aequorea victoria*. The gene was introduced in the fertilized ovules of the female rat, which gestates an animal that will have fluorescent skin under UV light. One application was to mark cancer cells and see how they travel around the body.

The Genetic Ancestor

Ever since Darwin published his theory about the evolution of species, humans have sought to understand their origin in light of a diversity of ideas and theories. With the success of efforts to map the human genome, old evidence is gaining new strength. Many scientific teams used some 100,000 samples of DNA from all over the world to trace the process of human expansion back to a common ancestor—the "Mitochondrial Eve" that lived in sub-Saharan Africa some 150,000 years ago. She was not the only human female of her time, but she was the one that all present-day women recognize as a common genetic ancestor. The key to the trail is in DNA mutations.

Genetic material

Each time an organism is conceived, its genetic material is a fusion of equal parts received from its parents. Recovering this material throughout history is impossible because of the large number of combinations, so scientists use mitochondrial DNA from the cells as well as DNA from the chromosomes. Thus, following a single path for each sex, the possible combinations are reduced to a set of hereditary lines that are traceable over time. This method is possible when a cell's DNA, along with the various locations of the genes and recombinant areas, is known.



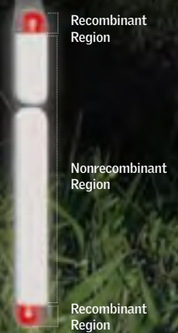
Spermatozoon
When a spermatozoon fertilizes an ovule, its tail breaks off, along with all cellular material except its nucleus, which contains half of the necessary genetic information for a new individual.

Ovule
This cell is a haploid cell that at the moment of fertilization provides the cellular organelles as well as half of the chromosomes. Among the organelles, the mitochondria are the most important for genetic studies.

Mitochondria
are the organelles that provide energy to the cell through respiration. They contain a portion of DNA.

Haplotype

is a set of closely linked alleles on a chromosome.



The Y chromosome

A baby's sex is determined by the sperm cell that succeeds in fertilizing the ovule. Specifically the male gender is determined by the Y chromosome, which is passed on from father to son. To follow a line of ascendant mutations in the recombinant part, the markers of each mutation must be read from the ends to the center to find a common male ancestor. He is called the chromosomal Adam, and he is estimated to have lived 90,000 years ago in Africa.

Mitochondrial DNA

Mitochondria contain circular DNA. This DNA has only one recombinable part, called HVR 1 and 2, where mutations can happen. Over time, the mutations leave marks that can be traced according to their location from the ends to the center. Because mitochondria are inherited from the mother, the mutations can be traced back to a female genetic ancestor. This "Mitochondrial Eve" lived in sub-Saharan Africa about 150,000 years ago. She was not alone at the time, nor was she the only one of her species. However, she was the only one of her community whose genetic inheritance survives.

Genetic Diversity and Phylogenetics

Geneticists have determined statistically that every three generations there is a mutation that will be preserved in the DNA of the descendants. They used this statistic and demographic studies to calculate the age of the "Mitochondrial Eve" and the "Nuclear Adam." If the path of mutations is followed from the present to the past, the line of ascent would lead to these genetic ancestors. However, in reverse, many mutations represent dead ends. That is, they left no descendants for a wide range of reasons. These links are part of the study called phylogenetics and make up well-defined haplogroups. Each haplogroup represents the genetic diversity of a species.

Genetic drift

Each time a mutation occurs, it continues as a mark on future generations. Genetic drift explains how this mutation spreads and how the effectiveness of its spread is related to the number of individuals in a group, the time they live in a certain region, and the environment. If the group is small, its chances of success are increased because genetic drift is more effective in changing the genetic pattern. Also, the longer the group remains in one place, the more mutations it will have.

Africa is where the greatest number of mutations is found. This leads to the supposition that humans have lived there the longest.

30,000-40,000 years ago
They spread to the rest of the world.

Haplogroup

is a human group with the same genetic descent, recognized by characteristic mutations.

L0 and L1, the most ancient
These haplogroups have the greatest number of mutations in their DNA and are the oldest human groups. They are the San and Khoekhoe peoples in Africa.

150,000 years ago
Homo sapiens is found only in Africa.

50,000-70,000 years ago
They migrate to other continents via the Red Sea.

The common relative

In genetic terms, DNA enables us to conceive of a primordial Adam and Eve, our genetic ancestors. However, the common ancestor of all humans alive today is quite a different matter. Several scientific hypotheses estimate that an ancestor to whom we are all related lived between 1,000 and 10,000 years ago.

Glossary

Acid

Type of chemical compound. DNA, vinegar, and lemon juice are weak acids.

Adaptation

A particular characteristic of an organism's structure, physiology, or behavior that enables it to live in its environment.

Allele

One of several alternatives of a gene. For example, the gene for eye color can have brown and blue alleles.

Amino Acid

One of the 20 chemical compounds that living beings use to form proteins.

Anthropologist

Scientist who studies human beings from the viewpoint of their social and biological relationships.

Archaeologist

Scientist who studies human history based on the objects humans have left behind, such as buildings, ceramics, and weapons.

Artificial Fertilization

Technique for fertilizing ovules. It is usually done in vitro, after which the fertilized ovule is implanted.

Artificial Selection

As opposed to natural selection, human intervention in the process of speciation; breeding animals or plants to improve their traits is an example.

Bacteria

One-celled organisms that are prokaryotic (they lack a nucleus bound by a membrane). Some cause illnesses, others are harmless, and still others are beneficial.

Bacteriophage

Virus that only infects bacteria; used as a vector in genetic engineering.

Bioballistics

Recombinant genetic technique that consists of shooting small metal projectiles covered with DNA into a cell to penetrate the nucleus and recombine the genes in the desired manner.

Biologist

Scientist who studies living beings.

Bioprospecting

The taking of tissue samples from living beings to find genes that can be patented to obtain economic benefits.

Cell

Smallest independent unit that forms part of a living being.

Cell Nucleus

The central part of a cell, it contains the chromosomes and regulates the cell's activity. In some cells it is well differentiated. Other cells, such as some bacteria and red blood cells, have no nucleus.

Cellular Membrane

Flexible covering of all living cells that contains the cytoplasm. It is semipermeable and regulates the interchange of water and gases with the outside.

Chimera

In Greek mythology, a monster with the head of a lion, the body of a goat, and the tail of a serpent. In genetics, the hypothetical creation of one being from the parts of others.

Chromosomal Crossover

A step during meiosis that corresponds to the interchange of genes between diploid chromosomes and causes the recombination of genes.

Chromosome

Sequence of DNA coiled inside the nucleus of a cell. One cell usually has more than one chromosome, and together they make up the genetic inheritance of an individual.

Clone

A living being that is identical to another. It also refers to parts, such as organs or fragments of DNA, that are identical.

Cloning

Action of producing a clone.

Coevolution

When more than one species evolve together, and the changes in one cause the others to undergo modifications in mutual adaptation.

Cytoplasm

Watery or gelatinous substance that contains organelles and makes up most of the interior of the cell, except for the nucleus.

Cytosine

One of the four bases that make up the DNA molecule.

Descendant

Family member belonging to later generations, such as a child, grandchild, or great-grandchild.

Designer Baby

Human baby selected as an embryo based on a set of genetic traits chosen before its birth.

Diabetes

Disease that prevents the body from synthesizing the necessary amount of insulin, a protein essential for the body's proper functioning.

Diploid

Cell with two complete sets of chromosomes. It is represented by the symbol 2n.

DNA

Deoxyribonucleic acid; molecule in the shape of a double helix with codified genetic information.

DNA Footprint

The identification of a person by DNA; used in forensics.

DNA Sequencing

Obtaining the structure of bases that make up DNA. The long DNA chain is often divided into smaller fractions for study.

Dominant Gene

Gene that, when present in a pair of alleles, is always manifested.

Double Helix

Shape of two spirals in geometric space. The DNA chain has this shape.

Dyslexia

Disorder, sometimes genetically based, that causes difficulties with reading, writing, and speech.

Embryo

Product of an ovule fertilized by a sperm cell. It can develop into an adult organism.

Endoplasmic Reticulum

Group of narrow channels that transport various types of substances and molecules from one point to another inside a cell.

Enzyme

Protein that helps regulate the chemical processes in a cell.

Escherichia coli

Abundant bacteria often used in genetic experiments.

Eugenics

Science that seeks to improve humankind by selecting and controlling human genes. Its objectives are highly controversial.

Evolution

Gradual change in a species or organism; not necessarily an improvement. It was theorized by Darwin in his famous book *On the Origin of Species*.

Extinction

The disappearance of all specimens of one or more species.

Fertilization

Fusion of a male gamete with a female gamete, forming a zygote, which can develop into a new individual.

Filler DNA

Long, repeated sequences of DNA that do not provide genetic information. Also called junk DNA.

Forensics

Scientific discipline of the study of evidence of a crime.

Fossil

All traces of past life, even those that have not been petrified.

Gamete

Reproductive cell, also called sex cell, such as sperm and eggs.

Gene

Unit of information of a chromosome; sequence of nucleotides in a DNA molecule that carries out a specific function.

Generation

A "level" in the history of a family or species. There is one generation between parents and children.

Gene Therapy

Treatment of certain diseases of genetic origin by replacing the patient's defective gene(s) with the correct gene(s) to cure the disease.

Genetic Disease

Disease caused partially or wholly by a genetic disorder.

Genetic Engineering

The study of the application of genetics in relation to technological uses.

Geneticist

Scientist who studies genetics.

Genetic Mutation

Error in the copying of a cell's DNA. A few mutations can be beneficial and intensify the cell's original qualities. Mutations are believed to have generated the evolution of species. Most give rise to closed evolutionary lines.

Genetics

The study of DNA and genes.

Genetic Trait

Physical trait transmitted to an organism's descendants, such as hair color and height.

Genome

Complete set of genes of a species.

Haploid

From the Greek term *haplous*, "one"; a cell with only one set of chromosomes, unlike diploid cells. Gametes are haploid cells.

Helix

Geometric spiral shape equivalent to a curve along a cylindrical surface; the shape in which the DNA molecule is curled.

Hemophilia

A group of hereditary diseases caused by the lack of a clotting factor (the most important being Factors VIII and IX). Its most common symptom is spontaneous hemorrhaging.

Heredity

In genetics, all types of genetic material passed on by the parents to a descendant.

Hormone

Glandular secretion with the function of stimulating, inhibiting, or regulating the action of other glands, systems, or organs of the body.

Karyotype

Ordering of the chromosomes of a cell according to shape, number, or size.

Keratin

Protein found in skin, hair, and nails.

Ligase

Protein used by geneticists to join sections of DNA.

Lysosome

Part of the cell that breaks down and reuses worn-out proteins.

Meiosis

Type of double cell division that forms four daughter cells out of one cell, each one with one-half the chromosomes of the original cell; typical in the formation of gametes.

Mitochondria

Cellular organelle that combines food and oxygen to produce energy for the cell.

Mitochondrial DNA

Small amount of DNA contained in the mitochondria of the cell.

Mitosis

Cellular division that produces two genetically identical daughter cells. The most common form of cell division.

Molecule

Minimum quantity into which a substance can be divided without losing its chemical properties. The level immediately below it is the atom.

Monozygotic Twins

Twins who develop from a single zygote that splits in two, forming two genetically identical individuals.

Mummy

Human corpse preserved by artificial methods, which can be preserved for long periods of time. The genetic study of mummies provides much evidence about life in the past.

Natural Selection

Process in which only the organisms that are best adapted thrive and evolve. This selection is carried out without human intervention.

Nitrogenous Base

Type of chemical compound. Four distinct types of bases in DNA make up the genetic code, according to their combinations.

Organelle

Any organ of a cell, including mitochondria, ribosomes, and lysosomes. They carry out specific functions.

Ovule

Female gamete, or sex cell.

Pancreas

Organ that produces insulin, located below the stomach.

PCR (Polymerase Chain Reaction)

Technique for multiplying fragments of DNA using polymerase.

Phenotype

In biology, the visible manifestation of a genotype in a certain environment.

Phylogenetics

The study of evolutionary relationships between the various species, reconstructing the history of their speciation.

Preimplantation Genetic Diagnosis

Method of in vitro selection of embryos based on preferred genetic conditions. They are then implanted in the uterus for normal development.

Protein

Natural or synthetic compound of amino acids, which carries out important functions in an organism.

Radioactivity

Energy given off by certain chemical elements; it can cause genetic alterations or even diseases such as cancer.

Recessive Gene

Gene that, even though present, might or might not be manifested in a pair of alleles depending on the presence of a dominant gene.

Recombinant DNA

Sequence that contains a combination originating from one or more organisms.

Replica

Exact or nearly exact copy of an original. A virus creates replicas of itself after invading a cell.

Repressor

Protein that binds to a DNA chain in order to stop the functioning of a gene.

Reproduction

Sexual or nonsexual creation of other organisms of the same species. The fertilization of gametes is sexual, whereas parthenogenesis is not.

Restriction Enzyme

Protein in certain bacteria that can cut the DNA molecule.

Ribosome

Part of a cell that reads the instructions of the genes and synthesizes the corresponding proteins.

RNA

Ribonucleic acid, similar to DNA but used to transport a copy of DNA code to the ribosome, where proteins are manufactured.

RNA Polymerase

Enzyme that serves as a catalyst for synthesizing an RNA molecule based on DNA code.

Selective Breeding

The production of plants or animals that display the results of artificial selection of their genetic traits. Agronomists, veterinarians, and geneticists use selective breeding to improve certain species and breeds or varieties to achieve, for example, greater productivity and crop yields.

Sex Cells

Special cells, also called gametes, with a reproductive function. Some examples are ovules, spermatozoa, and pollen.

Speciation

Evolutionary process in which a new species is formed, for various reasons, from another species.

Species

The lowest unit of classification in evolution. It was originally defined according to the phenotype of each individual. The field of genetics has raised new questions about what constitutes a species.

Spermatozoon (Sperm)

Male gamete or sex cell.

Stem Cell

Cell with the ability to develop into a specific type of cell or bodily tissue. Pluripotent stem cells can develop into any type of cell of the body.

Telomerase

Protein for repairing the telomere of a chromosome. Found only in certain cells.

Telomere

DNA sequence at the end of a chromosome, it is shortened every time the cell divides. The number of times the cell can divide depends on the length of the telomere.

Thymine

One of the four bases that make up DNA, combining in different sequences to form genes.

Transcription

Process of copying a strand of DNA onto a complementary sequence of RNA with the enzyme RNA polymerase.

Transgenic

Describes plants or animals of one species that have undergone genetic modifications using one or more genes from another species.

Vector

In genetic engineering, the agent that introduces a new sequence of DNA into an organism. Viruses and bacteria are often used as vectors.

Virus

Organism composed of DNA or RNA enclosed in a capsid, or protein structure. A virus can invade cells and use them to create more viruses.

X Chromosome

One of the chromosomes that determines a person's sex.

Y Chromosome

Chromosome that determines the male sex; passed on only from fathers to sons.

Zygote

The first cell of a sexually reproduced organism formed from the union of gametes.

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EVOLUTION AND GENETICS

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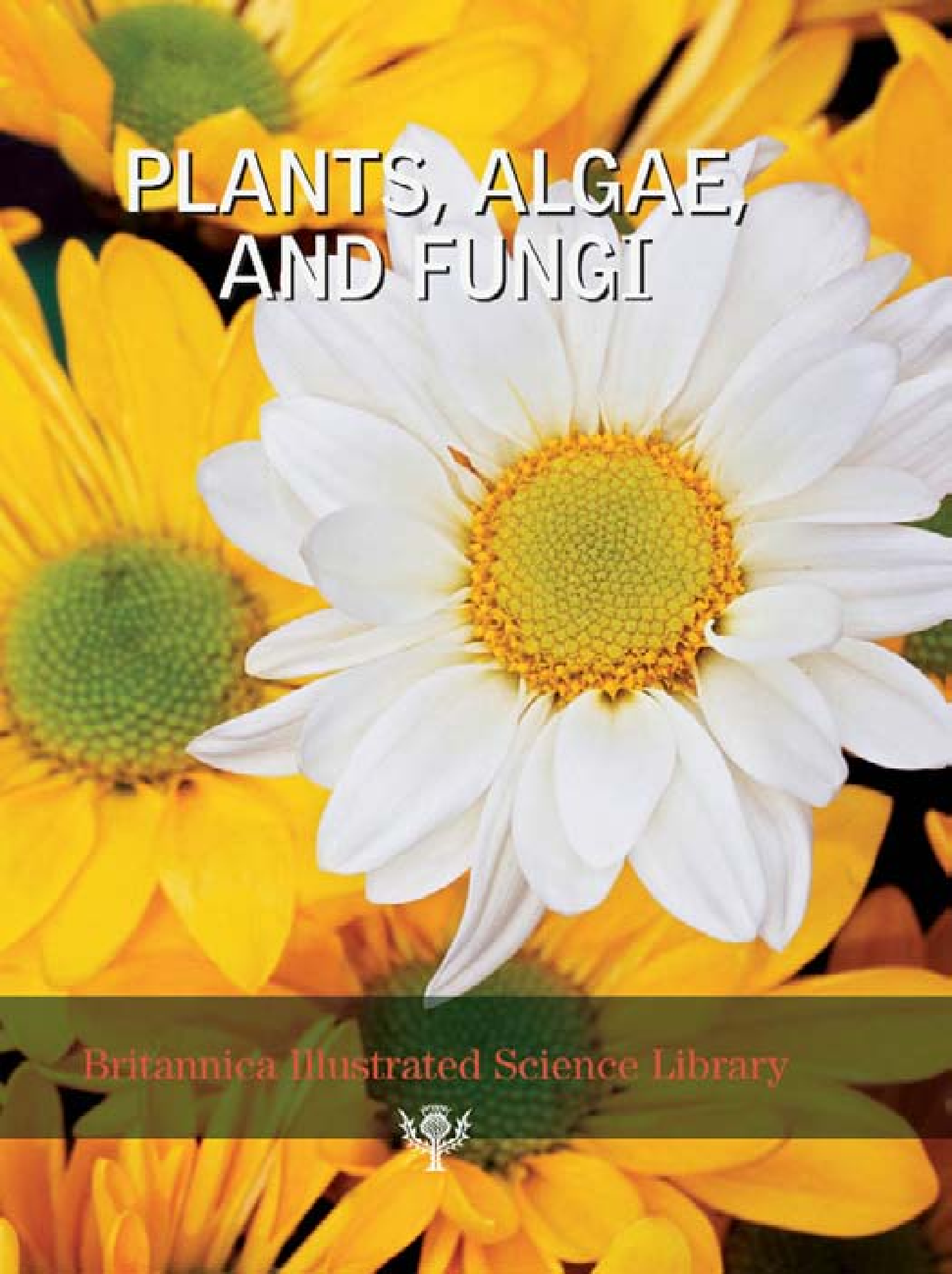
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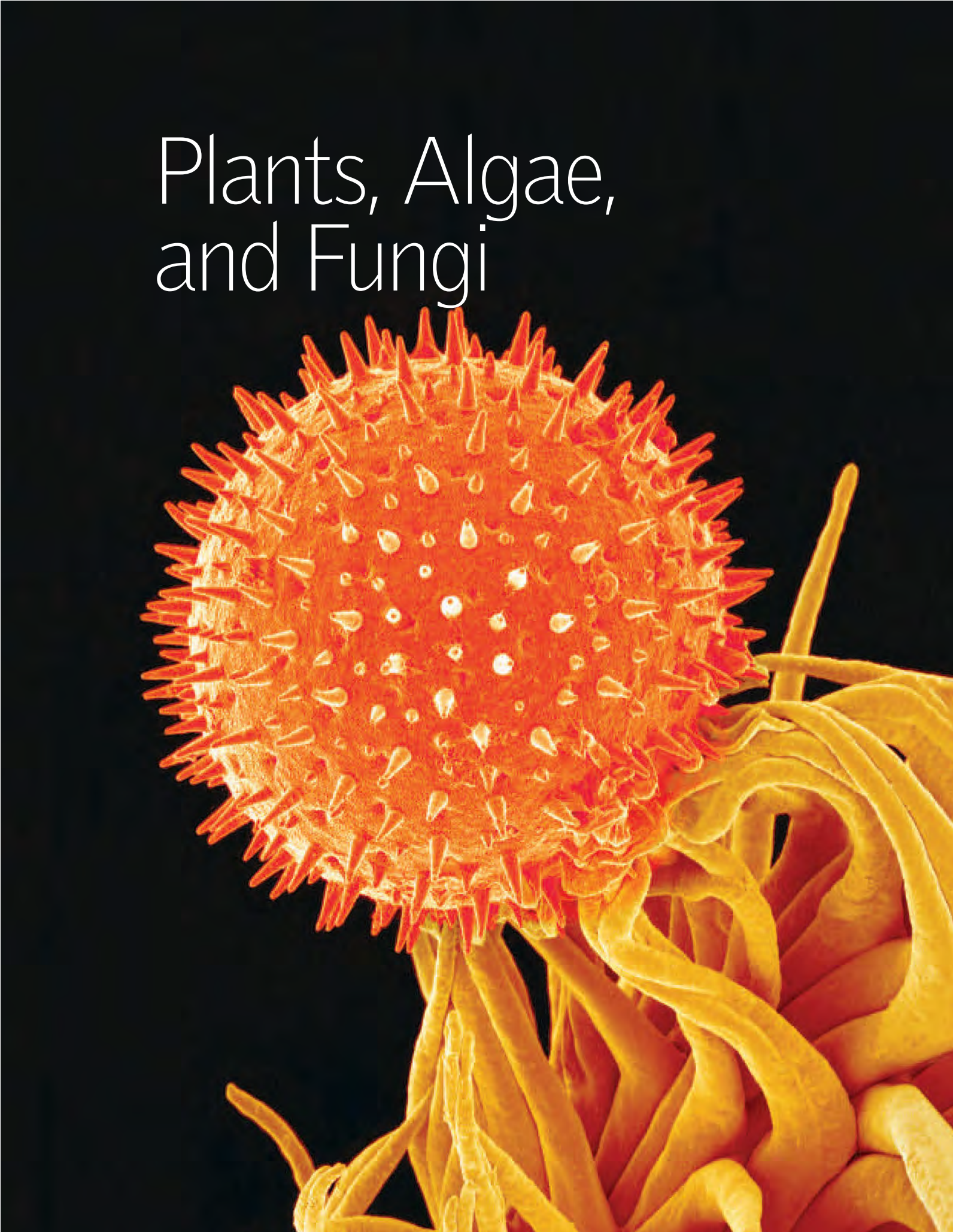

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Grain of mallow pollen, magnified 600 times, pictured on page 1. Pollen's function is to fertilize the female organs of the plant, a task that is achieved with the help of bees.

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Green Revolution

RICE CROP
Rice is synonymous with food security in much of Asia. It is also a staple food in western Africa, the Caribbean, and the tropical regions of Latin America.

There are approximately 300,000 plant species in the world, and they live in a variety of regions, from the frozen Arctic tundra to the lush tropical rainforests. Without plants we would not be able to live; they have always been intimately linked to life on Earth. Thanks to photosynthesis, plants provide us with food, medicines, wood, resins, and oxygen, among other things. Discovering plants' processes for converting sunlight into carbohydrates such as sugars and starches is almost magical. It is marvelous to understand how an organism that cannot move learned to maximize the energy that it receives from the Sun, as well as to discover the mechanisms that enable it to face so many different environmental challenges. Some leaves have essential adaptations, such as thick skin, thorns, or fleshy stalks, which allow them to survive in very dry environments. Others, such as the tomato plant, form certain proteins when temperatures drop in order to protect themselves from damage caused by freezing.

You may be surprised to learn why plants invest so much energy and effort into producing flowers. In this book we will describe for you in detail, step by step, how fertilization takes place. Did you know that pollination is aided by the wind and insects and that some flowers can be pollinated only by a certain species of insect? You will find all this and much more in the pages of this book, which includes spectacular images and illustrations that give an inside view of the core of a tree and even show the functions of its tissues and the veins of its leaves.

What were the first plants to conquer the Earth like, and how did they help convert bare rock into soil? What happened next, and which species evolved and spread worldwide during the Carboniferous Period? A complete historical overview of plants is included in this book, as is an explanation of the radical differences between plants, algae, and fungi—the latter two of which are now considered to be more closely related to animals than to plants. Although the place of plants in the human diet is nothing new, the search for other beneficial uses of plants is a more modern development. Crops—such as rice, corn, wheat, rye, barley, oats, soy, lentils, and chickpeas—are grown worldwide as sources of proteins, vitamins, minerals, and other nutrients necessary for our bodies to function, and they also provide people with an important source of income.

Background

GIANT SEQUOIA
Some trees of this species are found in central California.

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According to scientific evidence, the nearest relatives of plants are algae that lived on the shores of lagoons. Later, from these habitats, which were at times dry and at times damp, the first land plants emerged. Most had to adapt in order to prosper in a different environment. Such adaptation enabled them to achieve amazing growth, as exemplified by the giant sequoia *(Sequoiadendron giganteum)*, which can measure 260 feet (80 m) tall and 100 feet (30 m) in circumference at its base. Did you know that plants grow bigger as their cells multiply and expand? Many can grow 0.4 inch (1 cm) per day, and their growth can create enough pressure to open cracks in asphalt. ●

Kingdoms of the Quiet Life

Representing a vast array of life-forms, the plant kingdom includes approximately 300,000 species. Their most outstanding feature is the presence of chloroplasts with chlorophyll, a pigment that enables them to transform solar energy into chemical energy. They use this energy to produce their food. Plants need to attach themselves to a substrate (usually the ground), from which they can extract water and nutrients. This attachment, however, also keeps them from moving from place to place. Algae and fungi were once included in the plant kingdom, but they are now considered to be separate from plants and to belong to the kingdoms Protista and Fungi, respectively. ●

MOSS
Sphagnum sp.

RED MARINE ALGA
Rhodomela sp.

Algae

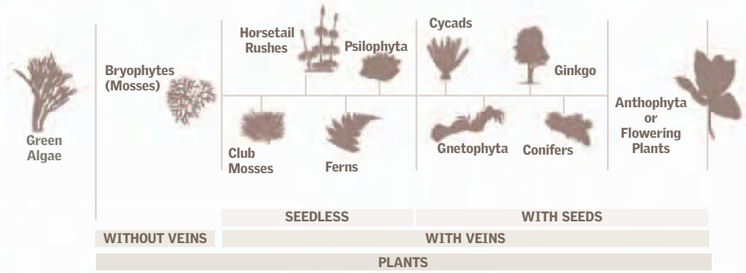
are commonly considered water plants, but this is not the case. Algae have neither roots nor stalks. Because they live in the water (freshwater or salt water), they need no substrate. Some are microscopic, but large algae formations can be found in the ocean. Algae are classified into families depending on their color. Together green algae and plants make up the group of organisms called the "green line," whose members are characterized by having chloroplasts and by storing grains of starch in the cytoplasm as a reserve.

Bryophytes

include mosses and worts. Mosses have rhizoids rather than roots. They can also absorb water through their entire body surface. Bryophytes lack a means of surviving long periods of drought. When dry periods come, bryophytes enter a latent state. Because they have no system of veins for transporting nutrients, they can barely grow beyond 0.4 inch (1 cm) long. In order to reproduce they need to be near liquid water.

Plants

The plant kingdom (Plantae) includes organisms whose characteristics include the presence of the pigment chlorophyll to convert solar energy into chemical energy for producing food from water and carbon dioxide. This ability is called autotrophy. All plants, whether large or small, play an extremely important role in providing food for all other living beings. Plants cannot move from place to place, but their gametes, spores (cells that separate from a plant and can germinate), and seeds can move about, especially with the help of water and wind.



SITKA SPRUCE
Picea sitchensis

CONIFERS
are the most abundant plants with seeds today. Their reproductive structures are called cones. Most conifers are evergreens.

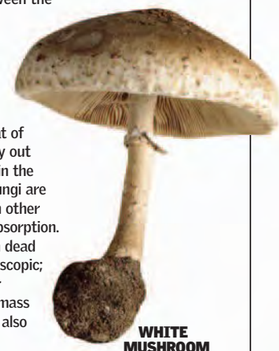
CYCADS
are tropical plants that look like palm trees. Their reproduction is similar to that of pine trees, but they are dioecious (each plant has flowers of only one sex).

GINKGOS
Only one species is left in this group, which is the oldest genus of living trees.

GNETOPHYTA
Plants with naked seeds and a vascular system similar to that of angiosperms

Gymnosperma

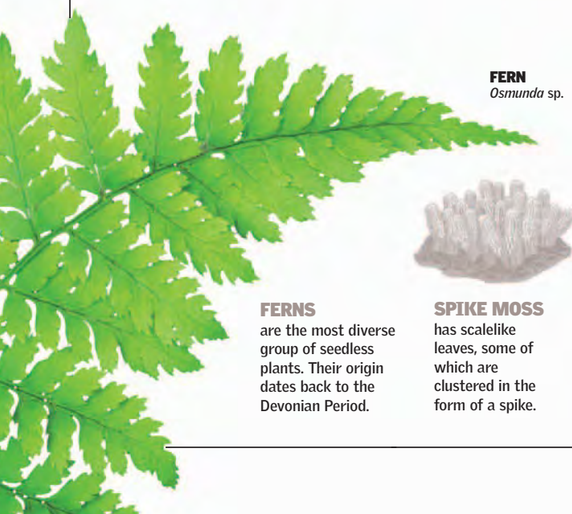
The Greek word means "naked seed." Gymnosperms are vascular plants with exposed seeds and no flowers. Ginkgos (Ginkgophyta) and cycads (Cycadophyta) were the most common plant groups in ancient times. Today conifers (such as pines, larches, cypresses, and firs) are the most common type. Conifers are monoicous—that is, the same plant has both male and female sexual organs—and their seeds are held between the scales of a structure called a cone.



WHITE MUSHROOM
Agaricus bisporus

Fungi

belong to a different kingdom from that of plants. Fungi, unlike plants, do not carry out photosynthesis, and they store energy in the form of glycogen rather than starch. Fungi are heterotrophic (they get their food from other organisms), and they take in food by absorption. Fungi can be either parasitic or feed on dead organic material. Some fungi are microscopic; others are large and conspicuous. Their bodies are composed of a mycelium, a mass of filaments called hyphae. Some fungi also have a fruit-bearing structure.



FERN
Osmunda sp.

FERNS
are the most diverse group of seedless plants. Their origin dates back to the Devonian Period.

SPIKE MOSS
has scalelike leaves, some of which are clustered in the form of a spike.

PSILOPHYTA
are extremely simple plants; they lack roots and true leaves, but they have a stalk with veins.

HORSETAIL RUSHES
have roots, stems, and true leaves. The leaves are small and encircle the stems.

Seedless

Ferns are the most common seedless plants today. Many are thought to have originated during the Devonian Period and reached their greatest splendor in the Carboniferous Period. Their tissues are simpler than those of plants with seeds, and their green stems have a large surface area, giving them a great capacity for photosynthesis. Ferns need water so that they can reproduce by means of spores. The spores are produced in spore cases called sporangia, which grow on leaves called sporophylls.

ORCHID
Cattleya trianae

ORCHIDS
have many petals; their number of petals is always a multiple of three. This makes them, along with cereal grains, monocotyledons (monocots).

WHEAT
Triticum sp.

Angiosperms

have seeds, flowers, and fruit. They include more than 250,000 species and are adapted to nearly all environments except for Antarctica. They reproduce sexually by producing flowers that later form fruits with seeds. Angiosperms have an efficient vascular system for transporting water (through the xylem) and food (through the phloem). Angiosperms make up a division of the plant kingdom that includes plants with bright flowers; grains, such as rice and wheat; other crops, such as cotton, tobacco, and coffee; and trees, such as oak, cherry, and chestnut.

CEREALS
are monocotyledons. Their seeds have only one cotyledon (embryonic leaf), and their mature leaves have parallel veins.

Aquatic Plants

These plants are especially adapted for living in ponds, streams, lakes, and rivers—places where other land plants cannot grow. Although aquatic plants belong to many different families, they have similar adaptations and are therefore an example of adaptive convergence. They include submerged plants and floating plants; plants that may or may not be rooted at the bottom; amphibious plants, which have leaves both above and below the water's surface; and heliophilic plants, which have only their roots underwater.

A Vital Role

Aquatic plants play an important role in the ecosystem not only for crustaceans, insects, and worms but also for fish, birds, and mammals because they are an important source of food and shelter for these categories of animals. Aquatic plants also play a major role in converting solar energy into the organic materials upon which many living things depend.

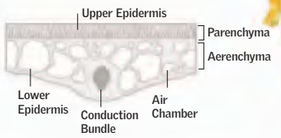
Rooted Plants with Floating Leaves

Such plants are often found in standing or slow-moving water. They have fixed rhizomes and petiolate leaves (leaves with a stalk that connects to a stem) that float on the surface of the water. Some of the plants have submerged leaves, some have floating leaves, and some have leaves outside the water, with each type having a different shape. In the case of floating leaves the properties of the upper surface are different from those of the lower surface, which is in contact with the water.

PARROT FEATHER
Myriophyllum aquaticum
This plant is native to temperate, subtropical, and tropical regions, and it is highly effective at oxygenating water.

TROPICAL WATER LILY
Victoria cruciana
It grows in deep, calm waters. Its leaves can measure up to 7 feet (2 m) across.

Floating Leaves
The rhizomes are fixed, the leaves grow on long stalks, and the leaf surface floats on the water.



YELLOW FLOATING HEART
Nymphoides peltata
It produces small creased yellow flowers all summer long.

LACHENALIA
Lachenalia viridiflora
This plant is attractive, with a large number of flowers.

Aquatic plant with especially beautiful flowers.

Amphibious or Wetland Plants

These species live on the edges of ponds, rivers, and swamps. They are also found in salt marshes, which are periodically flooded by tides or river overflows. These plants are a transition between aquatic and land plants. Their limiting factor is the availability of oxygen, so they have well-developed aerenchyma.

300 THE NUMBER OF WELL-KNOWN SPECIES OF WATER PLANTS

CATTAILS
Typha sp.
grow in moist soil, around lake margins, and in marshes in both temperate and tropical climates.

ARROWHEAD
Sagittaria sagittifolia
Its flowers, with three white petals and purple stamens, form during the summer.

Rooted Underwater Plants

The entire plant is submerged. The small root system serves only to anchor the plant since the stem can directly absorb water, carbon dioxide, and minerals. These plants are often found in flowing water. The submerged stems have no system of support—the water holds up the plant.

SAGO PONDWEED
Potamogeton densus
This water plant can be found in shallow depressions of clear-flowing streams.

HORNWORT
Ceratophyllum sp.
This plant has an abundance of fine leaves that form a conelike structure on each stem.

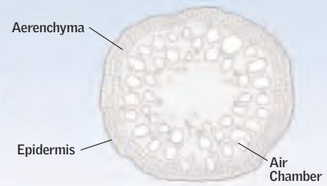
They produce and release oxygen as a result of photosynthesis.

Aquatic but Modern

The evolutionary history of plants began in water environments. They later conquered land by means of structures such as roots. Modern aquatic plants are not a primitive group, however. On the contrary, they have returned to the water environment by acquiring highly specialized organs and tissues. For example, some tissues have air pockets that enable the plant to float.

Aerenchyma

is always found in floating organisms. This tissue has an extensive system of intercellular spaces through which gases are diffused.



Submerged stems have no support system because the water holds up the plant. Their limiting factor is oxygen availability, so the aerenchyma helps make this substance available to the plant.

The roots and rhizomes under the water are well developed.

Submerged or Free

Some underwater plants are free, without roots, but with developed stalks and divided leaves. Other floating plants have a rosette shape and leaves modified for floating; they have well-developed roots with root caps but without absorbent hairs. The roots help the plant to stay balanced on top of the water.

KNOTWEED
Polygonum sp.
This aquatic plant grows in marshy vegetation.

BLADDERWORT
Utricularia vulgaris
These carnivorous plants complement their diet with small aquatic creatures.

EELGRASS
Vallisneria sp.
This oxygenating plant is found in ponds and aquariums.

The underwater parts do not have an impermeable outer layer, so they can absorb minerals and gases directly from the water.

Pneumatophores

are floating roots that are involved in air exchange. They take oxygen from the surface, and it circulates to the rest of the plant through its intracellular spaces. They probably also allow carbon dioxide to escape. Certain plants have a special adaptation that consists of air sacs that store oxygen for periods when the plant will be submerged or that speed up the plant's transpiration.

Conquest of Land

The movement of plants from shallow water onto land is associated with a series of evolutionary events. Certain changes in the genetic makeup of plants enabled them to face the new and extreme conditions found on the Earth's surface. Although land habitats offered plants direct exposure to sunlight, they also presented the problem of transpiration and the loss of water that it produces. This difficulty had to be overcome before plants could spread over land.

Vital Changes

Roots are among the most important adaptations for plants' success in land habitats. Root systems anchor the plant in the substrate and serve as a pathway for water and mineral nutrients to enter it. Besides roots, the development of a cuticle (skin membrane) to cover the entire plant's surface was crucial. Cells in the epidermis produce this waterproof membrane, which helps the plant tolerate the heat generated by sunlight and the wear and loss of water caused by the wind. This protection is interrupted by pores, which allow for gas exchange.

Green Revolution

Leaves are the main organs for photosynthesis in land plants. After plants appeared on land more than 440 million years ago, the amount of photosynthesis taking place gradually increased. This increase is believed to be one of the reasons the concentration of carbon dioxide in the atmosphere decreased. As a result, the Earth's average temperature also decreased.

50,000

SPECIES OF FUNGUS LIVE ALONGSIDE LAND-DWELLING PLANTS.

MOSS
***Sphagnum* sp.**
Bryophytes are the simplest of all land plants.

MALE FERN
Dryopteris filix-mas
These vascular plants need liquid water to reproduce.

Epiphytes

grow on plants or on some other supporting surface. Their anatomy includes secondary adaptations that enable them to live without being in contact with the soil.

Grasses

take advantage of long hours of summer daylight to grow and reproduce. Their stalks do not have reinforcing tissues that would enable them to remain erect.

SWEET VIOLET
Viola odorata
This plant's spring flowers have a pleasant scent.

STEMLESS SOW THISTLE
Sonchus acaulis
These plants lack a stem.

Giants

Trees are distinguished by their woody trunks. As a tree grows from a tender shoot, it develops a tissue that gives it strength, enabling it to grow over 330 feet (100 m) tall. Trees are found in the principal terrestrial ecosystems.

CHESTNUTS
Castanea sp.

WALNUTS
Juglans sp.

BEECHES
Fagus sp.

MAPLES
Acer sp.

OAKS
Quercus sp.

LINDENS
Tilia sp.

360 Feet
(110 M)

THE HEIGHT REACHED BY SOME SEQUOIA SEMPERVIREN TREES

Anatomy of a Tree

The oak tree is the undisputed king of the Western world. It is known for its lobed leaves and the large cap of its acorn, a nut found on all trees of the genus *Quercus*. The tree's main trunk grows upward and branches out toward the top. Oaks are a large group, containing many types of deciduous trees. Under optimal conditions oaks can grow to a height of more than 130 feet (40 m) and live an average of 600 years.

The leaves absorb CO_2 and produce sugars by means of photosynthesis.

Transpiration (the loss of water vapor) in the leaves pulls the xylem sap upward.

Flowers

The tree produces hanging male flowers, whereas female flowers are hidden among the leaves.

Buds

are formed by protective scales that fall off in the spring. They grow into new leaves and branches.

Climate

Trees grow in any place where there is sufficient water in the soil.

Trunk

The trunk is strong and grows straight upward. The top of the tree widens with branches, which may be twisted, knotted, or bent.

Bark

Growth Rings

Woodpeckers drill holes in the tree with their beaks as they look for insects.

Spring
The cycle begins as the first leaves appear.

Summer
The oak blossoms. It increases in height, and its trunk grows thicker.

Autumn
Low temperatures weaken the branches.

Winter
The leaves fall away; the tree is dormant until spring.

Leaves

are arranged one leaf to a stem on alternating sides of the twig. They have rounded lobes on either side of the main vein.

Summer
The leaves undertake photosynthesis, and the rest of the tree uses the sugars it produces.

Autumn
The cells at the end of each leaf stem weaken.

Winter
The leaf falls away, and the tree remains dormant.

Spring
New leaves begin to replace the old ones.

The xylem transports water and minerals from the roots to the rest of the tree.

The phloem transports sugars from the leaves to the rest of the tree.

Oak-Tree Products

The bark is rich in tannin, which is used in curing leather and as an astringent. The wood is strong and resists rotting.

Acorns

have dark stripes along their length. Their caps have flat scales.

Achene: A hard seed that does not split open at maturity

Remains of the Carpel (female reproductive part)

600 years

THE AVERAGE LIFE SPAN OF AN OAK

Beginnings

In its first year of life an oak tree's roots can grow nearly 5 feet (1.5 m).

Energy Source

The chlorophyll traps energy from sunlight and uses it to convert water and carbon dioxide into food.

Surface

Mosses use the bark of oak trees as a source of moisture.

Seeds

Some species have sweet-tasting seeds; others are bitter.

Absorption of Water and Minerals

Roots

grow sideways to form a deep, broad root system.

Feeding on Light

An important characteristic of plants is their ability to use sunlight and the carbon dioxide in the air to manufacture their own complex nutrients. This process, called photosynthesis, takes place in chloroplasts, cellular components that contain the necessary enzyme machinery to transform solar energy into chemical energy. Each plant cell can have between 20 and 100 oval-shaped chloroplasts. Chloroplasts can reproduce themselves, suggesting that they were once autonomous organisms that established a symbiosis, which produced the first plant cell.

Why Green?

Leaves absorb energy from visible light, which consists of different colors. The leaves reflect only the green light.

Leaves

are made of several types of plant tissues. Some serve as a support, and some serve as filler material.

Algae

perform photosynthesis underwater. Together with water plants, they provide most of the atmosphere's oxygen.

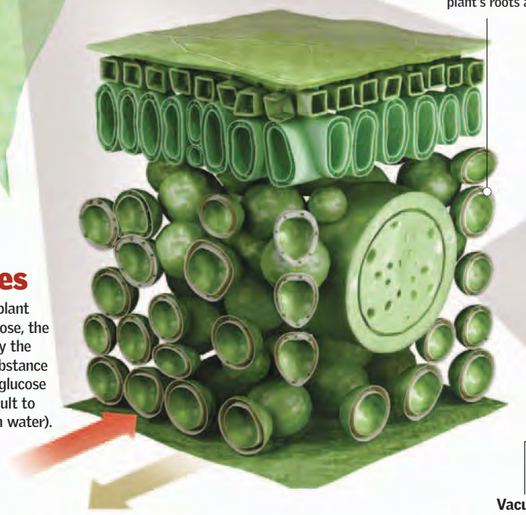
O_2 IS RELEASED BY PLANTS INTO THE EARTH'S ATMOSPHERE

CHLOROPHYLL
is the most abundant pigment in leaves.

WATER
Photosynthesis requires a constant supply of water, which reaches the leaves through the plant's roots and stem.

Plant Cells

have three traits that differentiate them from animal cells: cell walls (which are made up of 40 percent cellulose), a large vacuole containing water and trace mineral elements, and chloroplasts containing chlorophyll. Like an animal cell, a plant cell has a nucleus.

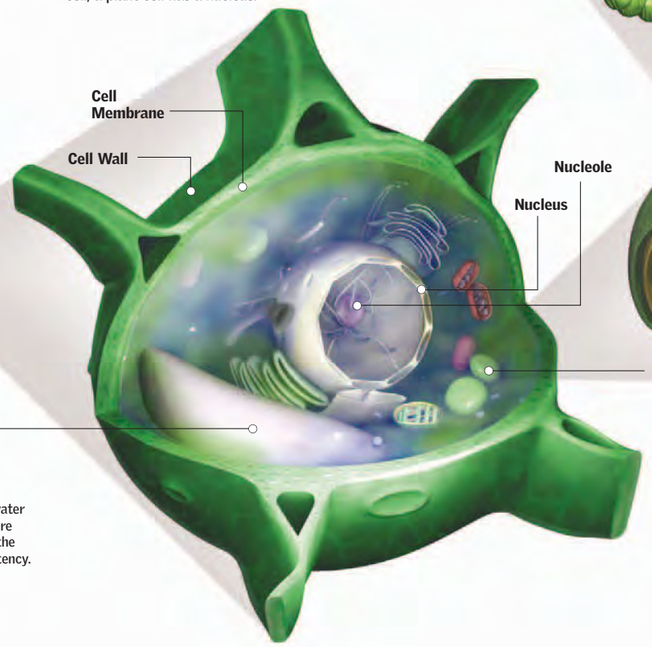


Plant Tissues

The relative stiffness of plant cells is provided by cellulose, the polysaccharide formed by the plant's cell walls. This substance is made of thousands of glucose units, and it is very difficult to hydrolyze (break down in water).

CARBON DIOXIDE
is absorbed by plant cells to form sugars by means of photosynthesis.

OXYGEN
is a by-product of photosynthesis. It exits the surface of the leaves through their stoma (two-celled pores).



Vacuole
provides water and pressure and gives the cell consistency.

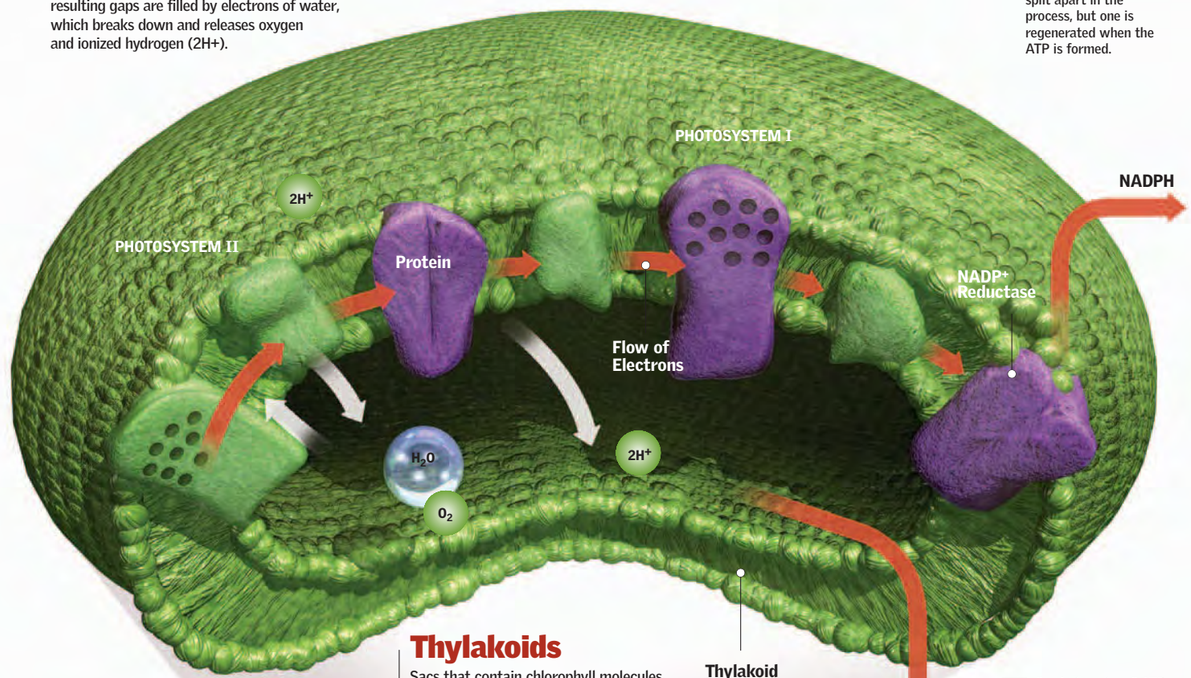
Stages of the Process

Photosynthesis takes place in two stages. The first, called photosystem II, depends directly on the amount of light received, which causes the chlorophyll to release electrons. The resulting gaps are filled by electrons of water, which breaks down and releases oxygen and ionized hydrogen (2H+).

1 ATP formation is powered by the movement of electrons into receptor molecules in a chain of oxidation and reduction reactions.

2 In photosystem I light energy is absorbed, sending electrons into other receptors and making NADPH out of $NADP^+$.

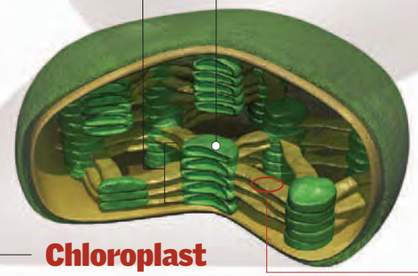
3 The ATP and NADPH obtained are the net gain of the system, in addition to oxygen. Two water molecules are split apart in the process, but one is regenerated when the ATP is formed.



4 In photosystem I ATP is also generated from ADP because of the surplus flow of free electrons.

Thylakoids

Sacs that contain chlorophyll molecules. Inside them ADP is converted into ATP as a product of the light-dependent phase of photosynthesis. Stacked thylakoids form a structure called a grana.

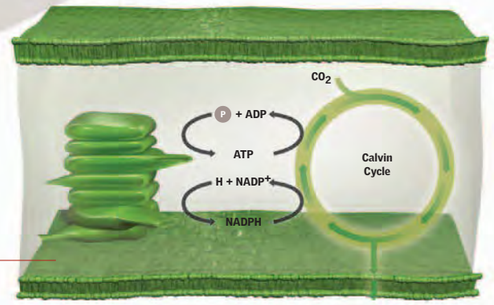


Chloroplast

The part of the cell where both phases of photosynthesis take place. It also contains enzymes.

Stroma

is the watery space inside the chloroplast.



The Dark Phase

This phase, so called because it does not directly depend on light, takes place inside the stroma of the chloroplast. Energy in the form of ATP and NADPH, which was produced in the light-dependent phase, is used to fix carbon dioxide as organic carbon through a process called the Calvin cycle. This cycle consists of chemical reactions that produce phosphoacylglycerides, which the plant cell uses to synthesize nutrients.

END PRODUCTS
enable the plant to generate carbohydrates, fatty acids, and amino acids.

Carbon
THE BUILDING BLOCK OF ORGANIC MATERIALS

From Algae to Ferns

DIATOMACEOUS ALGAE
The scientific name of this type of single-celled algae is *Biddulphia laevis*. It is usually found close to the surface of very shallow bodies of water.

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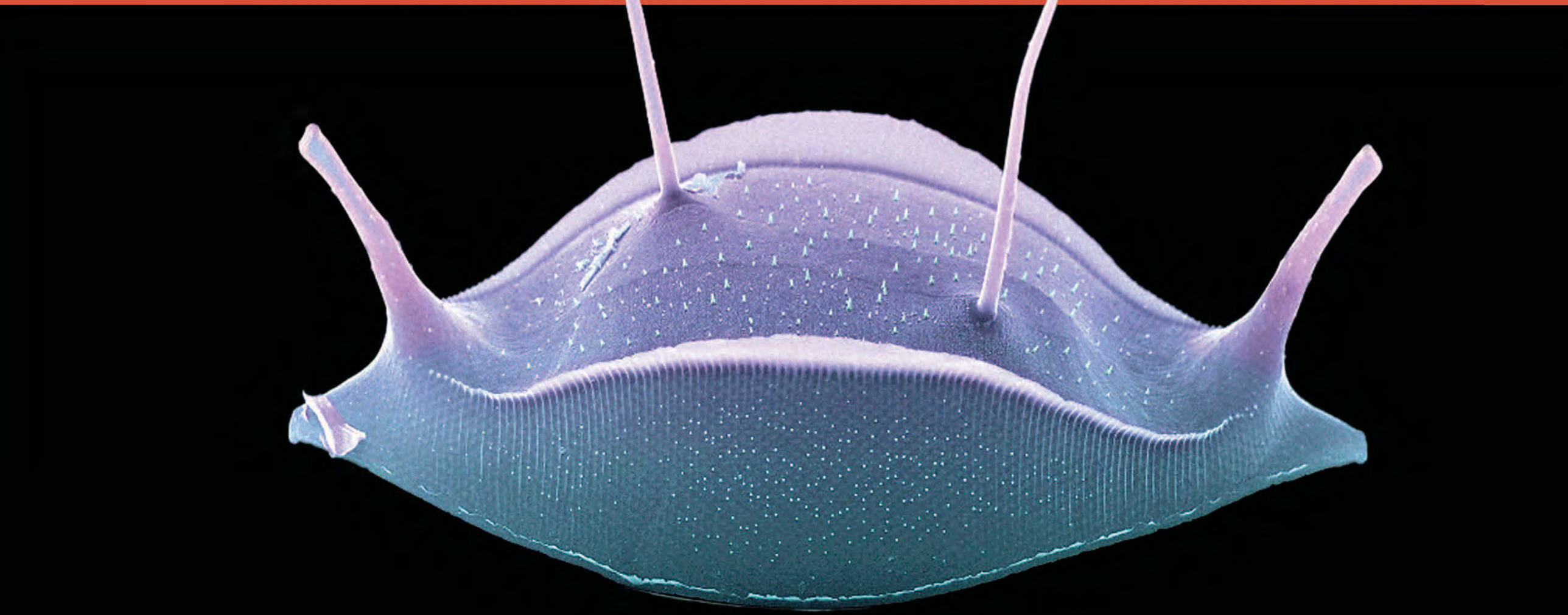
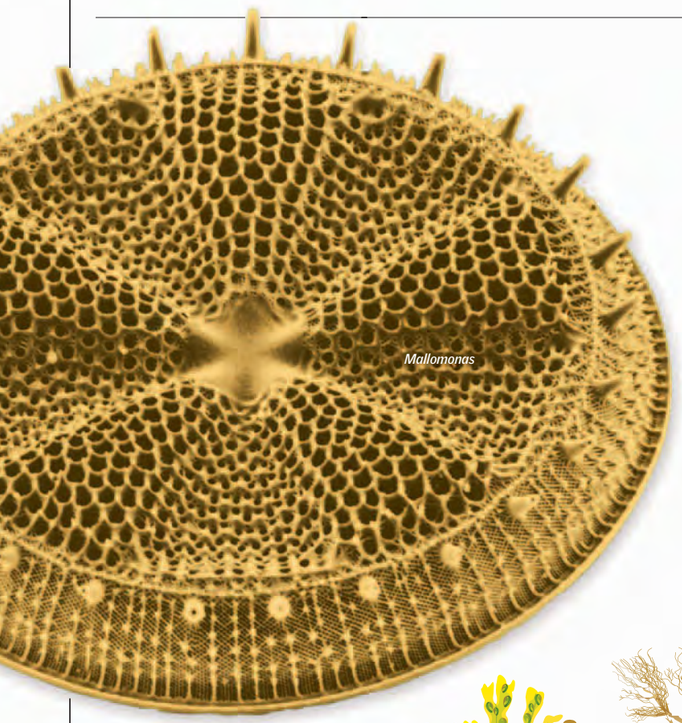


Algae (including seaweed) do not belong to the plant kingdom, because they do not have all the characteristics and functions of plants. Algae have neither roots nor stems. Because they live in water, they do not need these structures for absorbing water. Algae grow on the sea floor or on the surface of rocks in the ocean, in rivers, and in lakes. Their shape and color are extremely varied. The annual world harvest of algae is estimated at more than 1 million tons in dry weight. Asian countries (Japan and China) produce 80 percent of the world's harvest. Algae are used in agriculture, the food industry, pharmaceuticals, preservatives, and medicine. They are an important source of income for many workers. ●

Colors of Life

Algae are living things that manufacture their own food using photosynthesis. Their color is related to this process, and it has been used as a way of classifying them. They are also grouped according to the number of cells they have. There are many kinds of one-celled algae. Some algae form colonies, and others have multicellular bodies. Some types of brown seaweed can reach a length of more than 150 feet (45 m).



Mallomonas

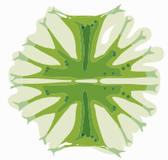
Single-Celled Organisms

often have flagella that enable them to move through the water. Most have the ability to ingest solid material through phagocytosis. Single-celled algae include some distinctive groups. Diatoms are covered with a protective shell made of silicon. Some single-celled algae, namely red algae, can thrive at relatively high temperatures. Red algae is unique among eukaryote organisms in its ability to live inside thermal water vents.

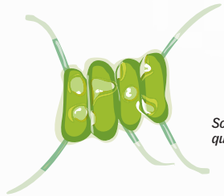
GREAT OPPORTUNISTS
Single-celled algae live near the surface of bodies of water. When they find an area with light and the nutrients necessary for development, they use asexual reproduction to multiply and colonize the area.

Multicelled Organisms

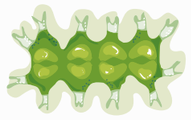
This group of algae includes multicelled structures. They form colonies with mobile, single-celled algae that group together more or less regularly in a shared mucilaginous capsule. They can also appear in threadlike shapes, which branch off, or in bulky shapes, which are made up of layers of cells with a particular degree of cellular differentiation, that together are called a thallus.



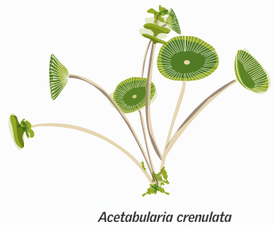
Micrasteria rotata



Scenedesmus quadricauda

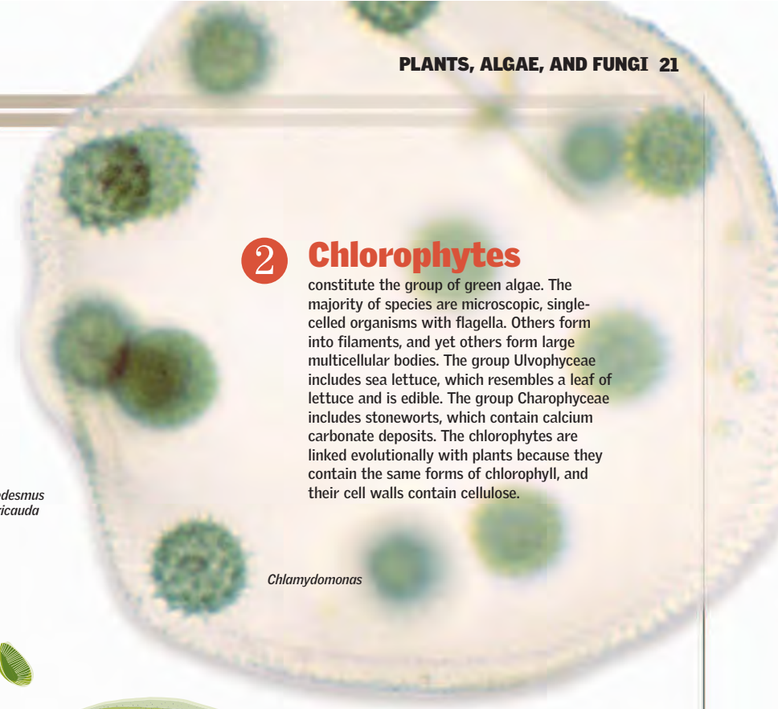


Micrasteria staurastrum



Acetabularia crenulata

Pinnularia borealis



Chlamydomonas

2 Chlorophytes

constitute the group of green algae. The majority of species are microscopic, single-celled organisms with flagella. Others form into filaments, and yet others form large multicellular bodies. The group Ulvophyceae includes sea lettuce, which resembles a leaf of lettuce and is edible. The group Charophyceae includes stoneworts, which contain calcium carbonate deposits. The chlorophytes are linked evolutionally with plants because they contain the same forms of chlorophyll, and their cell walls contain cellulose.

6,000
DIFFERENT SPECIES
have been classified within this group of green algae, or chlorophytes.

Carrageen red seaweed

1 Phaeophytes

are the 1,500 species of brown seaweed. They inhabit temperate regions and the rocky coasts of the coldest seas on Earth. Their color comes from the pigment fucoxanthin, a xanthophyll that masks the green color of their chlorophyll.

Fucus vesiculosus

Dictyota dichotoma implexa

Dictyota dichotoma hudson lamouroux

Cystoseira amantacea stricta

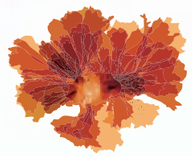
Ectocarpus siliculosus

3 Rhodophytes

are characterized by their phycoerythrin pigments, which give the algae a reddish color by masking their chlorophyll's green color. Most rhodophytes grow below the intertidal zone near tropical and subtropical coasts. They are distributed throughout the principal oceans of the world and grow mainly in shaded areas in warm, calm water.

Hypoglossum hypoglossoides

Bangia atropurpurea



Nitophyllum punctatum

Halymenia floresia

Apoglossum ruscifolium

How Algae Reproduce

The reproduction of algae can be sexual or asexual in alternating phases, depending on the species and on environmental conditions. Vegetative multiplication occurs through fragmentation or through the production of spores. In sexual reproduction the fertilization of the gametes (sexual cells) produces a zygote that will give rise to a new alga. During asexual reproduction there is no genetic exchange, and the algae produced are clones of the original. Sexual reproduction, in contrast, produces algae with new characteristics that may help them to better adapt to their environment.

Asexual

Asexual reproduction does not involve fertilization. It can take place in either of two ways. In fragmentation, segments of an alga become detached from its body, and, since the alga does not have any specialized organs, the segments continue to grow as long as environmental conditions remain favorable. The other form of asexual reproduction is by means of spores, special cells that form from a normal cell. Some algae spores have one or more filaments, or flagella, that allow the alga to swim freely. When the appropriate environmental conditions are found, the spores germinate into new algae.

ZOOSPORE
A structure that can produce a new individual asexually

Sexual

Sporophytes generate spores in every species of microscopic algae. New individuals born from these spores are called gametophytes, and they produce gametes, which can be male, female, or hermaphrodite. During fertilization the male gametes (antheridia) and the female ones (ovum) form a cell called a zygote, which develops into a new thallus when it grows. Gametocytes and sporophytes can vary in morphology. If they are similar, they are called isomorphic, and if they are different, they are called heteromorphic.

MALE FUCUS
The male fucus has receptacles in which antheridia form.

1 Antheridium

The male gametangia (structure that produces gametes). They produce antherozoids, which have two flagellae and are smaller than the ovum, or female gamete. They swim until they reach an ovum and then surround it.

JOURNEY
Once they become detached, antherozoids use their flagella to move in the water.

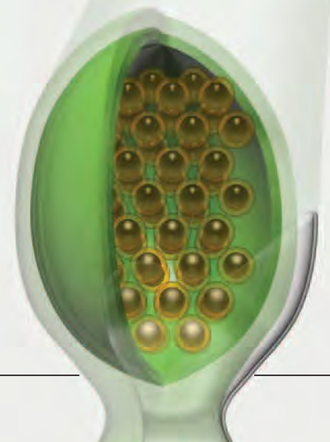
Transverse cut from a *Fucus* species thallus

OPENING
The sac that contains the ovum opens.

APPROACH
The journey of the antherozoids coincides with the opening of the female gametangia.

1 Ovum

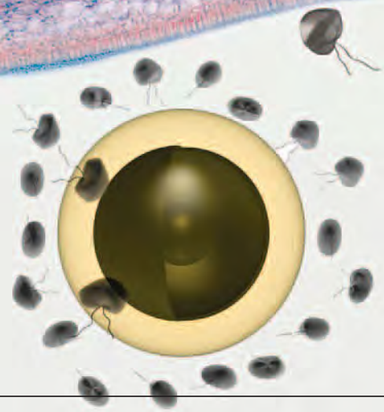
In the reproductive stage female gametangia form at the tips of the thalluses. This is where the female sexual cells (ova) develop.



FEMALE FUCUS
The receptacles secrete a greenish gelatin made up of female gametes. The gametes are freed when the sac that contains them breaks.

2 Fertilization

Both fertilization and asexual reproduction are the natural means of perpetuation for this species. Algae form new individuals similar to themselves through reproduction. When an antherozoid penetrates the ovum, it fertilizes the egg and forms a zygote.



3 New Thallus

After fertilization the zygote divides and creates the embryo, a small cell mass that attaches to rocks, where a new thallus of *Fucus* species grows. The thallus looks similar to the stem of plants, and it contains blades that look like leaves.

ANOTHER CYCLE
The youthful thallus, when mature, produces spores.

Terrestrial and Marine Algae

As long as there is water, the survival of an alga is assured. Algae are found both in the oceans and in freshwater, but not all can survive in both environments. Depth, temperature, and salt concentrations of water are characteristics that determine whether algae can live in a given area. Algae can be green, brown, or red. Of the three, red algae are found in the deepest waters. Some species of algae can live outside of water, but they are nevertheless found in humid places, such as in mud or on stone walls or rocks.

2 Concentration of Salts

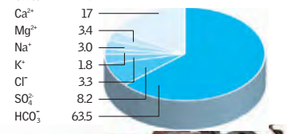
The waters that cover the Earth's surface are classified into two types: salt water, which forms the oceans and seas, and freshwater, or continental water. Marine water has a concentration of dissolved salts that is generally considered to be uniform. In contrast, the salt concentration of continental water can vary from place to place, causing it to have a different effect on living organisms.

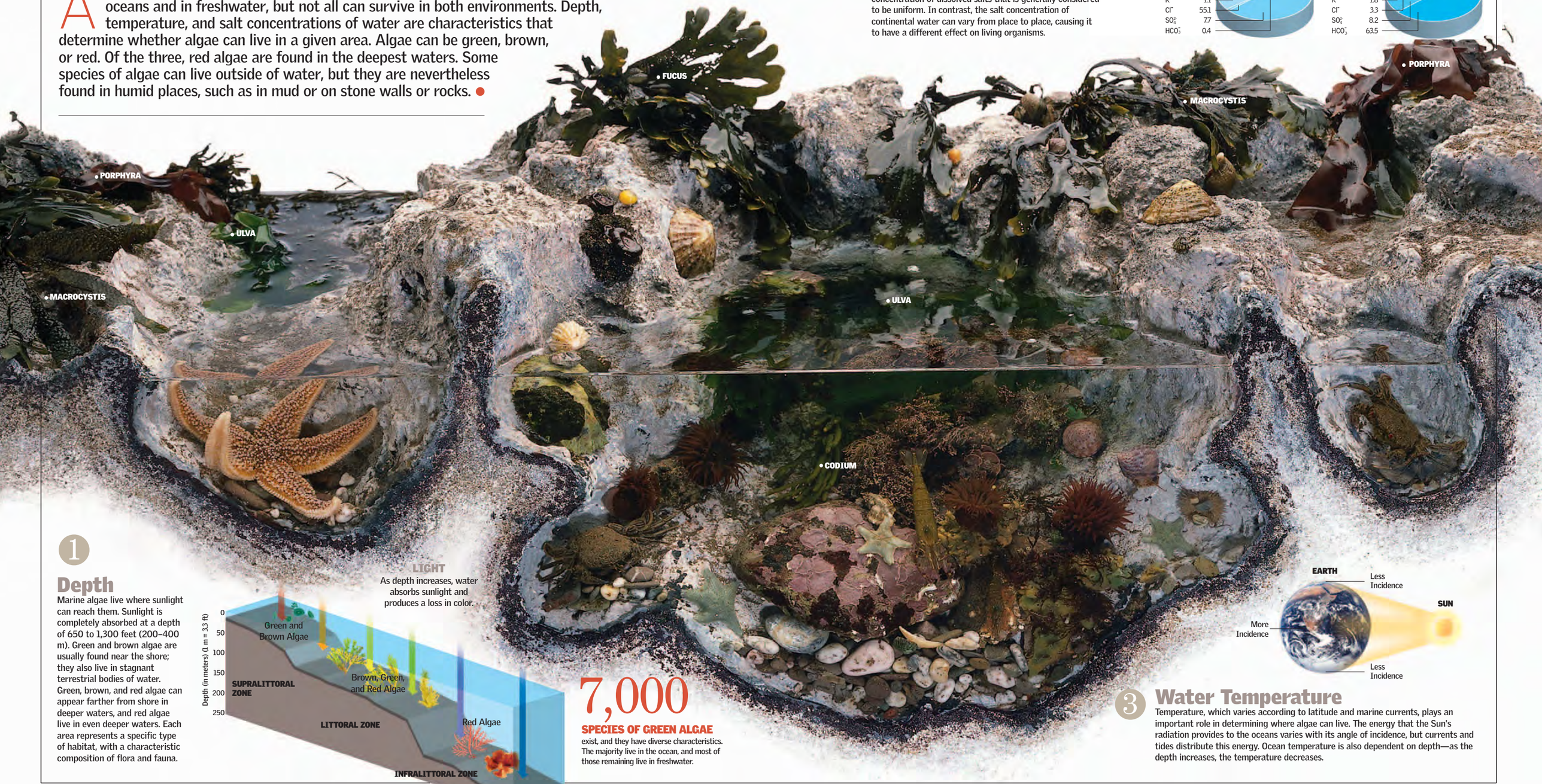
MARINE WATER

Salts	%
Ca^{2+}	1.2
Mg^{2+}	3.7
Na^{+}	30.6
K^{+}	1.1
Cl^{-}	55.1
SO_4^{2-}	7.7
HCO_3^{-}	0.4

FRESHWATER

Salts	%
Ca^{2+}	17
Mg^{2+}	3.4
Na^{+}	3.0
K^{+}	1.8
Cl^{-}	3.3
SO_4^{2-}	8.2
HCO_3^{-}	63.5

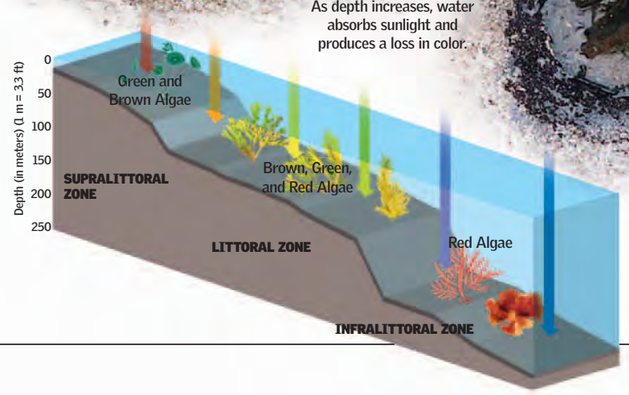




1 Depth

Marine algae live where sunlight can reach them. Sunlight is completely absorbed at a depth of 650 to 1,300 feet (200–400 m). Green and brown algae are usually found near the shore; they also live in stagnant terrestrial bodies of water. Green, brown, and red algae can appear farther from shore in deeper waters, and red algae live in even deeper waters. Each area represents a specific type of habitat, with a characteristic composition of flora and fauna.

LIGHT
As depth increases, water absorbs sunlight and produces a loss in color.



7,000
SPECIES OF GREEN ALGAE
exist, and they have diverse characteristics. The majority live in the ocean, and most of those remaining live in freshwater.

3 Water Temperature

Temperature, which varies according to latitude and marine currents, plays an important role in determining where algae can live. The energy that the Sun's radiation provides to the oceans varies with its angle of incidence, but currents and tides distribute this energy. Ocean temperature is also dependent on depth—as the depth increases, the temperature decreases.

The Algae Industry

In China algae have been used for food, as well as for traditional medicine, for thousands of years. However, the algae industry began on a broad scale in the 17th century in Japan with the production of caustic soda and potassium hydroxide from the ashes of brown algae. A century later Western countries began to exploit algae in order to extract iodine and other chemical compounds of great economic value, such as phycocolloids (gelatin-like substances that can be obtained from several species of algae). The most commonly used phycocolloids are agar, carrageenan, and algin.

Dulse
Palmaria sp.

How Agar Is Obtained

Most algae collection is still done by hand, although commonly used large species, such as the Caribbean Sargasso, are also collected with special boats in which processing of the algae can begin. The first stages, especially drying, are typically carried out by natural methods, but large fire-heated drying drums are used in some countries of Europe and North America. Although the use of heated drums is more expensive, it can result in a product of higher quality.

1.5
TONS PER DAY
The amount of *Gelidium* algae extractd by hand in Japan.

REGENERATION
In order for the algae to grow back, only 40 percent of it is harvested.

DRYING
prevents the algae from rotting. Algae are first washed with seawater.

COLLECTION
Large algae are collected with cranes from a boat; small algae are collected by hand or with rakes.

ALGAE BUNDLE
If the algae are dried properly, they can be stored for years.

13 feet
(4 M)
The depth at which Sargasso is collected.

1

Alkalinization

After the dry bundles are gathered, the algae are transported to an alkaline treatment pond. There sodium hydroxide (NaOH) is added, and the mixture is heated to a temperature of 176° F (80° C). The mixture is then washed and hydrated with cold water.

START
The algae are given an alkaline pH.

WASHING
They are washed with water; then acid is added.

COOKING
The mass is cooked with a pH of 6.5 or 7.

BASINS
can withstand high temperatures. In the last basin the mass is cooked at 212° F (100° C).

2

Washing and Bleaching

After the alkaline treatment algae pass through a process in which they are washed with cold water. To ensure an even processing, compressed air is bubbled through the water. Later sodium hypochlorite is added to bleach the algae. Some sulfuric acid can be added to this mixture to regulate acidity.

2 hours
THE APPROXIMATE LENGTH OF TIME THE ALGAE IS COOKED

DRY ALGAE
Properly processed, gelatin can be obtained from these algae.

FILTERING
The noxious residues are eliminated. Then the algae are filtered and transported to a tank.

FILTER

GELLING

POOL
The pool receives the mixture free from rock or shell matter, and a mechanism in the tank slowly stirs the mixture.

GELATIN
contains 1% agar.

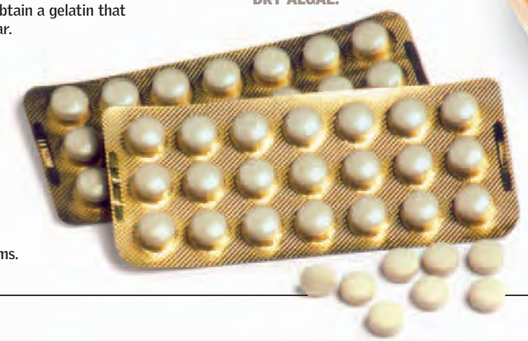
GELLING
occurs when the temperature is lowered along the length of the pipe to 77° F (25° C).

3

Transformation

An initial filtering step uses only water and a filtering soil. The mixture must be kept in continuous motion and injected with steam to prevent it from separating. The mixture then passes through stainless steel pipes in which it is cooled to obtain a gelatin that contains 1 percent agar.

IN MEDICINE
Agar has laxative properties. Agar is also used as a medium for culturing microorganisms.



A World of Uses

Algae extracts are used in the manufacture of food products, medicines, cosmetics, medical supplies, and even tools. They can serve as emulsifying, stabilizing, thickening, or clarifying agents. Algae extracts are used in ice cream pie fillings, puddings, and salad dressings. They are also used for making molds in dentistry, for lubrication in drawing wire, and as a medium for culturing bacteria.

150 pounds
per square inch (10 kg/sq cm)
IS THE PRESSURE AT WHICH HOT AIR IS APPLIED TO DRY THE MASS.

CRUSHED ALGAE
Bleaching with salt water improves its quality.

GRINDING

DRYING BELT

MOIST GEL

HOT AIR
160-175° F
(70-80° C)

PRESS

DRYING PRESS

4

Drying

Gel sheets about 0.4 inch (1 cm) wide come out of the press between layers of nylon. They are placed on platforms, where they begin to dry. The sheets are then placed on a conveyor belt and further dried by a stream of hot air.

9 pounds
(4 kg)
THE QUANTITY OF FRESH ALGAE NEEDED TO OBTAIN ABOUT 2 POUNDS (1 KG) OF DRY ALGAE.

PRECAUTION
The dried algae must be ground immediately to prevent it from becoming moist.

MILLING
The dry ground agar is milled to reduce particle size.

QUALITY CONTROL
Samples are taken during successive stages of sifting.

5

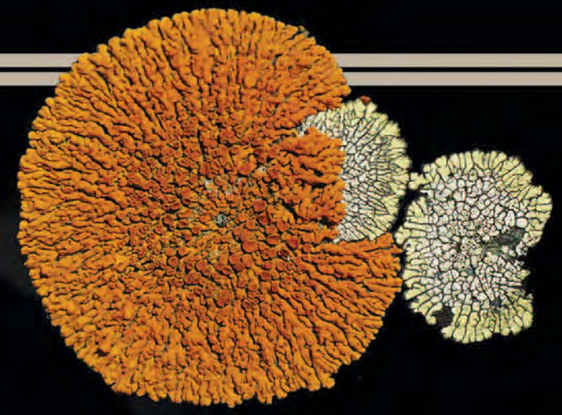
Finishing

Ground into a powder, the product must go through successive milling and sifting steps to eliminate any lumps and impurities. Samples are taken as the algae product is refined. Once it has passed inspection, the final product is packaged.

COLLOID
Algae extract is soluble only in hot water. It is used to add consistency to dairy products such as cheese, as well as to other food products.

Strange Bedfellows

Lichens are the result of a close relationship between fungi and algae (usually green algae). Although they are most common in cold areas, they adapt easily to diverse climatic conditions. Lichens can grow in the Arctic glacial regions, as well as in deserts and volcanic regions. They live on rocks, from which they obtain all the necessary minerals to live, and they contribute to the formation of soils. Lichens are excellent indicators of the level of environmental pollution, since elevated levels of pollution cause them to die.



Crustaceans

With an appearance of scales, tightly affixed to the substratum, they can be continuous or fragmented in plates or areolas.

Physcia caesia

0.04 to 0.08 inch (1-2 mm)

Where They Live

Lichens grow in cold regions, as well as in the Amazon Rainforest and the desert. They are very sensitive to environmental pollution.

Corticolas
In trunks and branches

Terricolas
In the soil of forests

Saxicola
On rocks and walls.

Fructicose

The long-branched thallus is raised or hanging and can resemble small trees or entangled bushes.

Pseudoevernia sp.

0.08 to 0.15 inch (2-4 mm)

IN THE MOUNTAINS
This lichen is common on the bark of mountain conifers. Its thallus looks like horns.

STIPES
The stipes are projections on the surface of the thallus at which vegetative multiplication takes place. Their shape is variable, and their color may be the same as or slightly darker than that of the thallus.

A Symbiotic Relationship

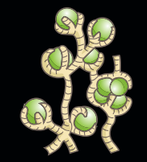
Lichens are the result of symbiosis between a fungus and an alga, a relationship from which both benefit. In a lichen the fungus offers the alga support and moisture and protects it from heat and dehydration. Likewise, the alga produces food for itself and for the fungus through photosynthesis.

HOW IT IS CREATED

1 The spore of the fungus encounters the alga.

2 The spore grows around the alga, and the alga reproduces.

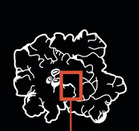
3 They form a new organism (thallus of the lichen).



Foliaceous

A showy lichen that has the appearance of widely spread leaves. It is the most common macrolichen.

Lobaria pulmonaria

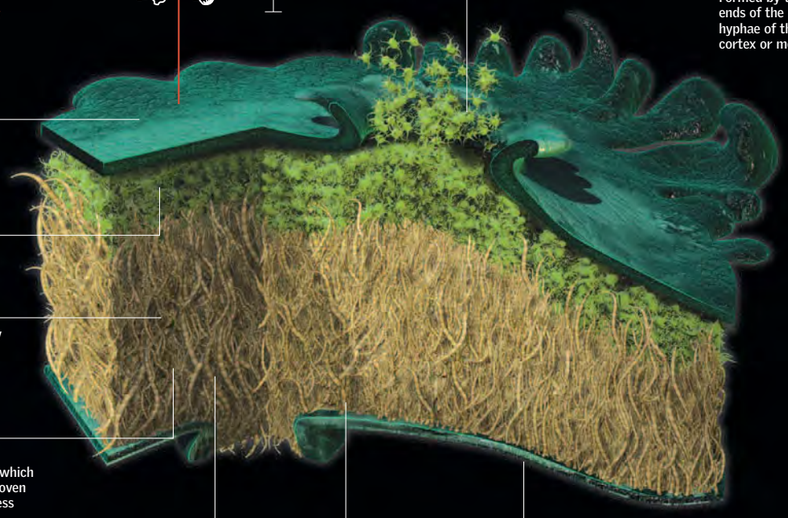


0.1 to 0.2 inch (3-6 mm)

APOTHECIA
intervenes in the reproduction of the fungus because it contains its spores.

SOREDIA
Unit of lichen dispersion, formed by groups of gonidia surrounded by hyphae

HAIRS
Formed by the ends of the hyphae of the cortex or medulla



LAYER OF ALGAE
The layer contains green algae, which carry out photosynthesis to feed the fungus.

GONIDIA
Name given to algae when they form part of a lichen

LAYER OF FUNGI
The fungi are generally ascomycetes. They provide the alga with the moisture it needs to live.

HYPHAE
Fungal filaments, which are interwoven and colorless

MEDULLA
Made up of fungus hyphae

RICIN
Fixation organs that arise from the cortex or from the medulla

CORTEX
External layer of the lichen

15,000
CLASSES OF LICHENS EXIST.

0.8 inch (2 cm)
THE AMOUNT A LICHEN CAN GROW IN A YEAR.

4,000 years
THE LIFE SPAN A LICHEN CAN ACHIEVE

Mosses

Mosses were among the earliest plants to emerge. They evolved from green algae more than 250 million years ago and belong to the group of simple plants called bryophytes. Mosses reproduce only in environments where liquid water is present. Because they grow in groups, they take on the appearance of a green carpet. These primitive plants can serve as indicators of air pollution, and they help reduce environmental degradation.

Fertilization

Reproductive organs that produce gametes develop in the green gametophytes, which live all year long. When there is sufficient moisture, the male gamete reaches a female gamete and fertilizes it. The zygote that arises from this union grows and forms the sporophyte. The sporophyte possesses fertile tissue that undergoes meiosis to generate spores that, after falling to the ground and germinating, will form a new gametophyte.

ZYGOTE
It forms from the union of two sexual cells in a watery environment.

DEVELOPMENT OF THE SPOROPHYTE
The zygote divides through mitosis and forms the sporophyte, which remains united to the gametophyte.

ADULT SPOROPHYTE
The adult sporophyte consists of a capsule (within which the spores form), a stalk (which holds the capsule), and a foot.

DIPLOID
Diploid cells have two sets of chromosomes. Consequently, they have duplicate genetic information.

Spermatozoids

Archegonium: the female sexual organ

Antheridium: the male sexual organ

Ovule

ADULT GAMETOPHYTE
This is what a grown gametophyte looks like.

HAPLOID
A haploid cell is one that contains only one complete set of genetic information. Reproductive cells, such as the ova and sperm in mammals, are haploid, but the rest of the cells in the body of higher organisms are usually diploid—that is, they have two complete sets of chromosomes. In fertilization two haploid gametes unite to form a diploid cell. In the case of mosses all the cells of the gametophyte, the gametes, and the spores are haploid.

GAMETOPHYTE DEVELOPMENT
The gametophyte grows.

HORIZONTAL FILAMENTS
The gametophyte develops from the horizontal filaments.

GERMINATION OF THE SPORE
The spore germinates and gives rise to a filamentous protonema (cellular mass).

Rhizoids

The Cycle of Life

Mosses do not have flowers, seeds, or fruits. As with other plants, mosses have a life cycle formed by alternating generations; however, in contrast with vascular plants, the haploid gametophyte is larger than the diploid sporophyte. Their biological cycle begins with the release of spores, which form in a capsule that opens when a small cap called the operculum is ejected. The spores germinate and give rise to a filamentous protonema (cellular mass) from which the gametophyte develops. The zygote that forms from the union of the two sexual cells develops into the sporophyte.

Capsule
Operculum
Sporophyte
Perichaetium
Stalk
Calyptra
Gametophyte
Rhizoid

Annulus

Operculum
A type of cap that covers the opening of the capsule and normally separates when the spores exit

Meiosis

Meiosis is a type of cellular division in which each daughter cell receives only one complete set of chromosomes. Therefore, the resulting cells have half as many chromosomes as the parent cells had. In general, this mechanism generates the gametes, but mosses generate haploid spores in the capsule of the sporophyte.

Mature Sporophyte
consists of a capsule in which spores are formed.

SPORES
The life cycle of a moss begins with the freeing of the spores that form in the capsule, which opens when a cap called the operculum is expulsed.

FUNARIA HIGROMETRICA
belongs to the group of plants called bryophytes.

Capsule
contains the spores and is found at the tip.

10,000
SPECIES OF MOSSES
have been classified within the bryophite group of nonvascular plants.

Small Plants

Mosses are bryophytes. They are relatively small plants that affix themselves to a substratum via rhizoids and carry out photosynthesis in small "leaves" that lack the specialized tissues of the real leaves of vascular plants. They fulfill a very important ecological role: they participate in the formation of soils by decomposing the rocks on which they grow, and they contribute to the photosynthesis of epiphytes in rainforests. Their asexual reproduction occurs through fragmentation or the production of propagula.

SPOROPHYTE
The sporophyte does not have an independent existence but lives at the expense of the gametophyte. The sporophyte lives a short time and only during a certain time of the year.

0.2 inch (5 mm)

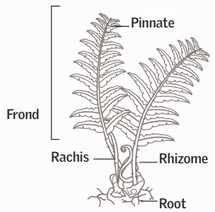
Dispersion of Spores

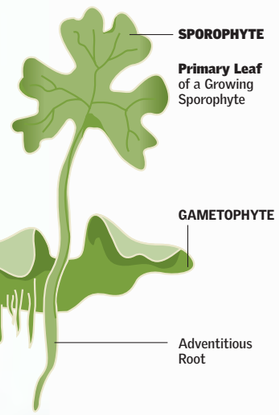
The fern is one of the oldest plants. Ferns have inhabited the surface of the Earth for 400 million years. Their leaves have structures called sori that contain the sporangium, which houses the spores. When the sori dry up, they release the spores into the air. Once on the ground, the spores germinate as gametophytes. In times of rain and abundant moisture the male cells of the gametophyte are able to swim to reach female gametes, which they fertilize to form a zygote that will grow as a sporophyte.

CIRCINATE VERNATION
The manner in which fronds expand from a bud by unfurling from the tip

1 Birth

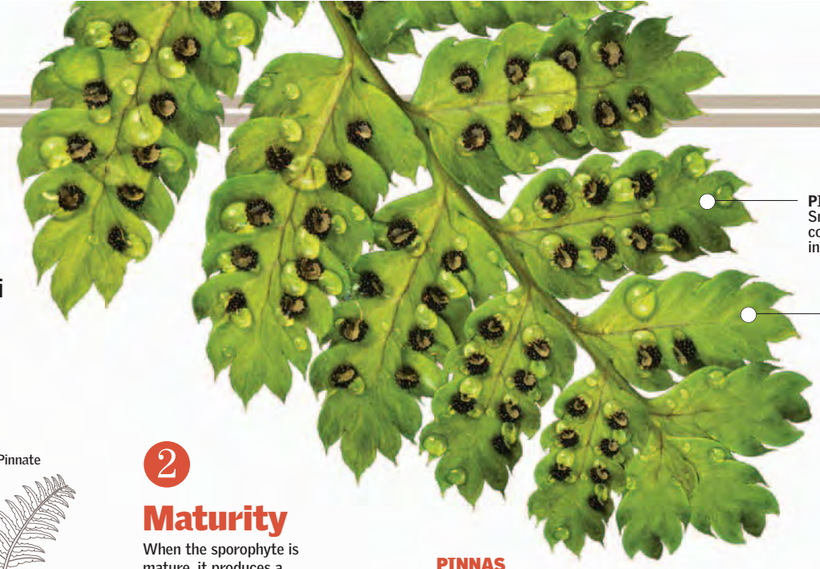
The zygote develops into a structure called a sporophyte; it is the part visible to the naked eye. In some cases it has the appearance of a **serrated leaf.**

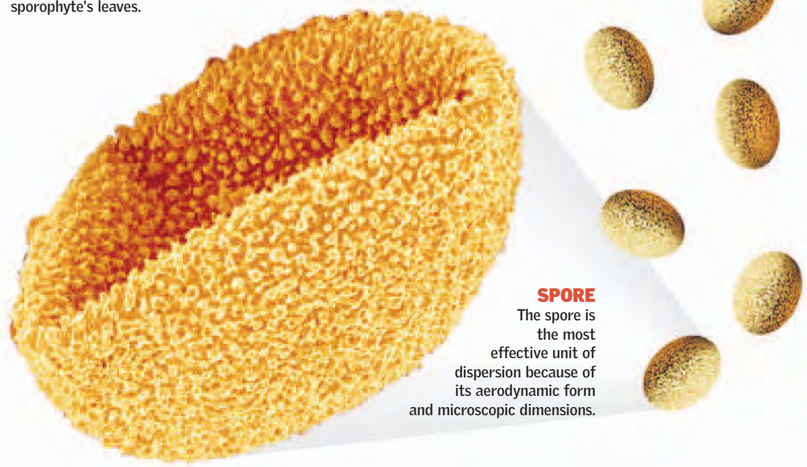




2 Maturity

When the sporophyte is mature, it produces a large number of **sporangia** that group together, forming sori on the back of the sporophyte's leaves.

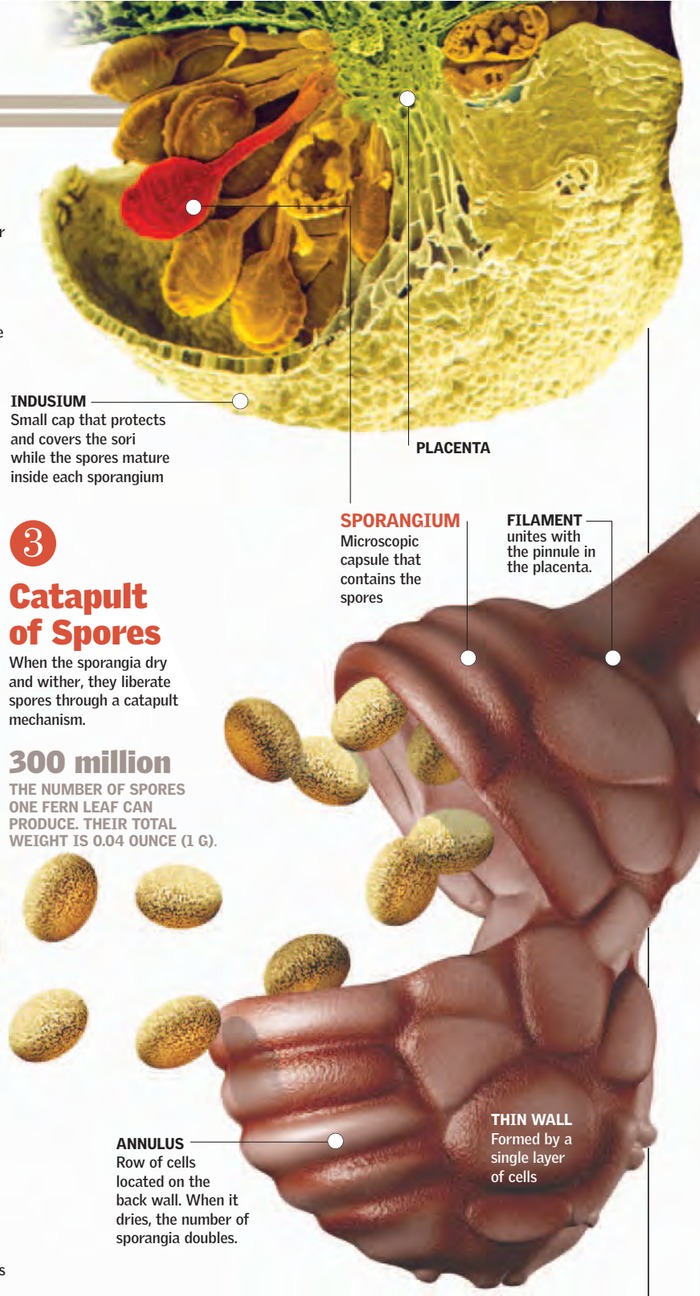




3 Catapult of Spores

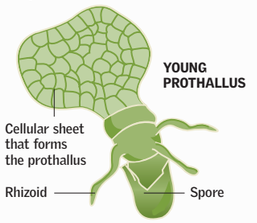
When the sporangia dry and wither, they liberate spores through a catapult mechanism.

300 million
THE NUMBER OF SPORES ONE FERN LEAF CAN PRODUCE. THEIR TOTAL WEIGHT IS 0.04 OUNCE (1 G).



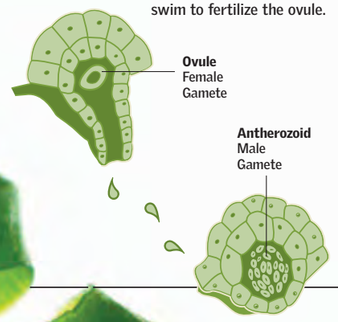
4 Germination

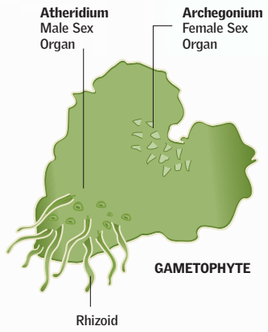
When the spore encounters the right environment, it develops into a multicellular structure that forms the **haploid gametophyte**, called the prothallus.



5 Fertilization

The male and female organs are differentiated in the prothallus. In the presence of liquid water the antheridia swim to fertilize the ovule.





12,000
SPECIES OF FERNS CAN BE FOUND IN THE WORLD.

HOW A LEPTOSPORANGIUM IS FORMED

A It starts as a single initial epidermal cell.

B The lower cell gives rise to a thin stalk.

C The stalk divides into four initial cells and small sporocytes.

D The wall of the mature sporangium is formed by a single layer of cells.

E It forms a fixed number of spores through meiosis.

Seed Plants

THE POLLEN REACHES THE STIGMA
This is the first step toward forming a seed. In this magnified image the grains of pollen can be seen on the stigma of wolfsbane *(Arnica montana)*.

SEEDS, TO AND FRO 36-39
UNDER THE EARTH 40-41
STEMS: MORE THAN A SUPPORT 42-43
WOODEN HEART 44-45
GROWTH SPRINGS ETERNAL 46-47
ENERGY MANUFACTURERS 48-49
FUNCTIONAL BEAUTY 50-51
POLLINATION 52-53
BEARING FRUIT 54-55
CONIFERS 56-57

Unlike animals, plants are limited in their ability to seek favorable conditions for life and growth. Consequently, they have evolved in different ways to reproduce and increase their population through seeds. A seed must arrive at an appropriate location at the best time for germination. Each species achieves its objective in a different way. Some produce a great number of seeds; others wrap their seeds in a layer of hard material that softens with rain and winter's cold to germinate in spring. In this chapter you will find how this process takes place, step by step, from pollination to the formation of a new plant.●

Seeds, To and Fro

Reproduction from seeds is the most prominent evolutionary advantage in plants' conquest of the terrestrial environment. The seed shelters the embryo of the future plant with protective walls. The embryo is accompanied by tissues that provide enough nutrients for it to begin to develop. Optimal temperature and an appropriate quantity of water and air are the factors that stimulate the seed to awaken to a marvelous cycle of development and growth that will culminate in the generation of new seeds.

1 Awakening of the Seed

Seeds, such as those of the field, or corn, poppy *(Papaver rhoeas)*, leave their latent stage when they hydrate and receive enough light and air. Their protective coverings open and the embryo grows thanks to the energy provided by its cotyledons, or seed leaves.

2 Tropism

Because of gravity, amyloplasts are always located in the lower part of cells. They produce a stimulus that encourages the root to grow toward the earth, a process called geotropism.

PLUMULE
The bud of a plant embryo that will produce the first shoot

COTYLEDON
The first embryo leaf. It provides the energy needed for growth.

Cell multiplication allows the stem to grow.

ABSORBENT HAIRS
These organs begin to develop in the radicle. They help the seed absorb water from the soil.

HARD COVER
Called the testa, it can appear in very different forms.

RADICLE
The embryo root that will produce the main root of the plant

The testa protects the embryo and the cotyledons during the seed's latent stage.

WATER
is responsible for breaking open seed covers because the hydrated tissues exert pressure on the interior of the seed.

NUTRIENTS
The radicle is in charge of collecting water and nutrients present in the soil.

Gibberellins

are plant hormones that, during the first stages of germination following water absorption, are distributed through the endosperm. Their presence promotes the production of enzymes that hydrolyze starches, lipids, and proteins to turn them into sugars, fatty acids, and amino acids, respectively. These substances provide nutrition to the embryo and later to the seedling.

3 Growth

The seedling grows and breaks through the surface. This causes the plant to be exposed to light so it can begin to carry out photosynthesis. It thus begins to manufacture its own nutrients to replace those provided by the cotyledons.

APICAL GROWTH
Light stimulates the multiplication of cells in the apex of the stem.

The cotyledon is carried by the vertical growth of the stem.

Cotyledons can remain under the soil or, as in this case, grow above the ground.

HYPOCOTYL
The first part of the stem that emerges and develops in the young plant

PRIMARY ROOT
It anchors itself to the ground and branches out to support the plant in the substrate.

4 Vegetative Growth

The first true leaves unfold above the cotyledons, and the stem elongates from formative tissue called the meristem, located at the apex of the plant. Continued growth will lead to the formation of an adult plant, which will develop its own reproductive structures.

TOTIPOTENCY
Characteristic of the vegetative apex cells

FIRST TRUE LEAVES

CONDUCTION
The stem carries water and minerals from the root to the leaves, while taking manufactured substances in the opposite direction.

0.4 inch (1 cm)
IS THE MAXIMUN HEIGHT IT CAN GROW IN ONE DAY.

SECONDARY ROOTS

The root has many fine hairs that create a large surface area for water absorption.

5 Production of the Flower's Parts

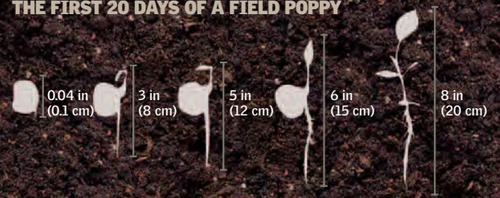
The apical bud begins to produce fertile flower structures (gynoecium and androecium) and sterile structures (petals and sepals). The flower bud forms.

FLOWERING
Internal and external changes stimulate the apical bud to develop a flower.

SESSILE LEAVES
The upper leaves have no petiole.

ALTERNATE LEAVES

THE FIRST 20 DAYS OF A FIELD POPPY



20 inches (50 cm)
THE TYPICAL HEIGHT OF AN ADULT FIELD POPPY PLANT

Autum

THE TIME OF THE YEAR IN WHICH THE SEED OF *PAPAVER RHOEAS* GERMINATES

6 Flowering

Once the bud opens, the parts of the flower begin to unfold. They are arranged in whorls, or cycles. The whorl called the corolla contains the petals, and two inner whorls contain the fertile parts of the flower—the androecium and gynoecium.

ANTHESIS
is the name given to the opening of the flower bud.

ALTERNATE LEAVES

COMPOSITES
The leaves are very divided and participate in photosynthesis.

The absorbent hairs are destroyed by abrasion from the soil but are constantly renewed.

ANDROECIUM
It produces male gametes.

Bees approach flowers in search of nectar and carry away grains of pollen that cling to their hairs.

POLLEN

7 Pollination

The mechanism by which flowering plants reproduce involves the dispersal of pollen.

4 inches (10 cm)
THE AVERAGE SIZE OF THE FLOWER

Pollination by Wind

Wind is an ideal means for transporting pollen over long distances.

Pollination by Animals

Animals, especially insects, help the plant disseminate its pollen after they enter the flower in search of food. This is one of the main mechanisms of pollination.

Stigma
Antera
Nectarium
Ovary

FRUIT
After fertilization the ovary and adjacent tissues become the fruit.

STAMENS

8 Fruit

The seeds develop inside the fruit. Each seed can develop a new seedling.

FRUIT
SEEDS

9 Ripe Fruit

The fruits scatter the seeds. Field poppies have dry fruits that open when they mature. This facilitates the dispersion of the seed by air.

SEMILLAS

10 Dispersion

The fruit of a field poppy is a capsule with small openings at the top that help scatter the seeds.

11 Seed

Each seed distributed by air, water, or an animal can, under the right environmental conditions, germinate and develop into a new seedling.

3,000
SEEDS CAN BE CONTAINED IN ONE RIPE FIELD POPPY FRUIT.

Something in Common

When a seed encounters the right conditions, it can begin its life cycle. Even though every species of plant with flowers has its own particular life cycle, the various stages of the cycle represented here are typical of angiosperms in general.

Under the Earth

The root is a plant organ that is usually found under the soil. It has positive geotropism; its main functions are absorbing water and inorganic nutrients and attaching the plant to the ground. The root is essential for identifying the particular characteristics of a plant. The anatomical structure of a root can vary, but, because it does not have leaves or nodes, it will always be simpler than that of a stem.

Types of Roots

Roots differ, depending on their origin. The primary root originates in the radicle of the embryo. An adventitious root is one that originates in any other organ of the plant. Roots are also subdivided according to their morphology.

TAPROOT
A taproot grows downward and has lateral secondary roots that are not well developed.

BRANCHED
The main root is divided, creating other secondary roots.

FIBROUS
The root system is formed by a group of roots of similar diameter.

TUBEROUS
Fibrous in structure, some of the roots thicken to store food for the plant.

NAPIFORM
The taproot thickens with stored food and tapers abruptly near its tip.

TABULAR
Tabular roots form at the base of a trunk and create a supporting buttress.

GEOTROPISM
Geotropism, or gravitotropism, is the growth of a plant or parts of a plant in a particular direction because of the stimulus of gravity. The force of gravity orients the stems and their leaves to grow upward (negative geotropism), whereas the roots grow downward (positive geotropism).

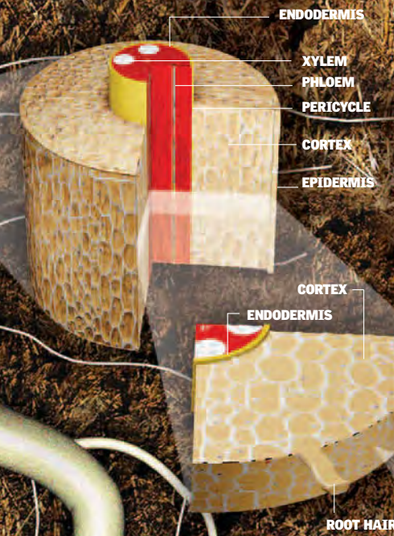
Monocotyledons

These plants have embryos with only one cotyledon. Their embryonic root generally has a relatively short life and is replaced by adventitious roots that grow from the stem.

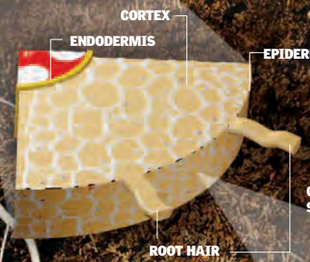
GROWTH AND CELLULAR DIVISION
Through the process of cell division a cell divides into two cells, each with its own nucleus. The new cells elongate, allowing the root to grow in thickness and length.

NECK
Transitional area between the root and the stem

BRANCHING AREA
A porous region whose function is to anchor and absorb

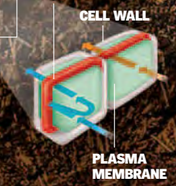


ROOT STRUCTURE
The root cap is found at one end. While the root grows, the root cap protects it from soil abrasion. The interior of the root is formed by the cortex, which has a compact layer of cells that affect the flow of water through the root. This is due to the presence of a waxy substance that forms the Casparian strip.



WATER
enters through the root hairs and travels to the epidermal cells.

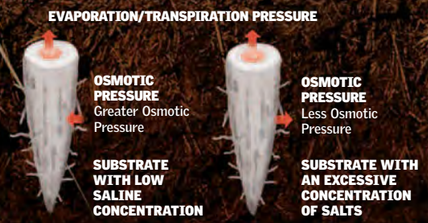
CASPARIAN STRIP



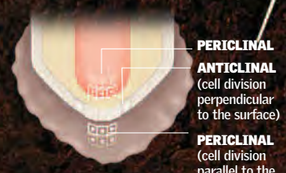
NUTRIENTS
depend on the quantity of nutrients in the soil and on the roots' ability to transport them.

PILIFEROUS AREA
The part of the root covered with slender elongations called roots hairs. The root hairs increase the surface area through which water and minerals can be absorbed.

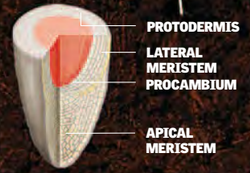
OSMOSIS
The process through which plants absorb water from the soil. Water penetrates into the roots when it has a greater concentration in the soil than in the intracellular environment of the root.



GROWTH AREA
Area of cell growth and elongation



ROOT CAP
The thimble-shaped structure that protects the meristem of the tip of the root as it penetrates the soil

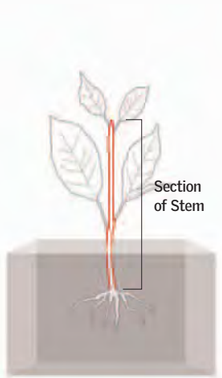


Dicotyledon

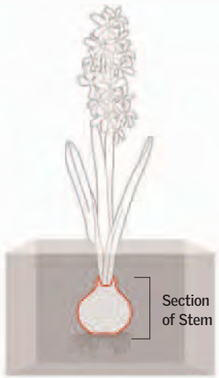
A plant that has seeds with two embryonic leaves (cotyledons). It has a tap root, and the leaves are usually petiolated with a reticulated vein distribution. Their internal organization consists of open conducting vessels in a circular arrangement.

Stems: More Than a Support

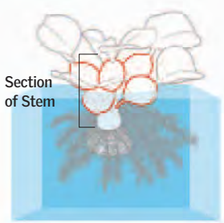
Stems, which occur in a variety of shapes and colors, support a plant's leaves and flowers. They keep it from breaking apart in the wind, and they determine its height. In addition, stems are also responsible for distributing the water and minerals absorbed by a plant's roots. Stems contain conducting vessels through which water and nutrients circulate. In trees and bushes, stems are woody for better support. ●



IN THE AIR
Stems are usually branched, as seen in trees and bushes.

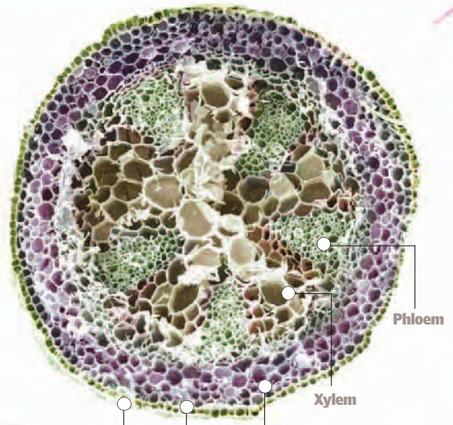


IN THE GROUND
Certain types of stems have unusual characteristics.



IN THE WATER
The stem of an aquatic plant can lie underwater.

CROSS-SECTION OF A NEW STEM



Development of Stems in Different Mediums

Stems have widely varying sizes and shapes that reflect different adaptations to the environment. Palm trees and wheat are two good examples that show how different mediums can modify the stem through evolution. Palm trees are the tallest non-woody plants. They grow tall because they must compete with many other plants for sunlight. In contrast, wheat is typical of areas with a cold climate and a short growing season. It develops a relatively short stem. This enables it to survive the physical assault of the dry wind and the loss of leaves.

COMMON POTATO
Solanum tuberosum

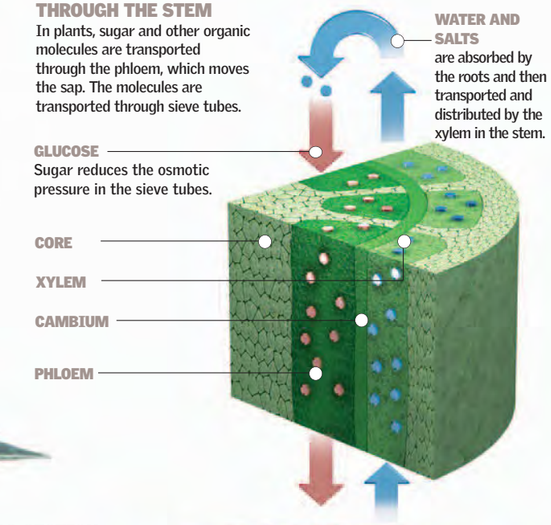
TUBER
An underground stem composed mainly of parenchymatic cells filled with starch. The potato's small depressions are actually axillary eyes. In an onion, another example of a plant with an underground stem, starch accumulates not in tubers but in thick leaves that grow around the stem.

ARTICHOKE THISTLE
Cynara cardunculus

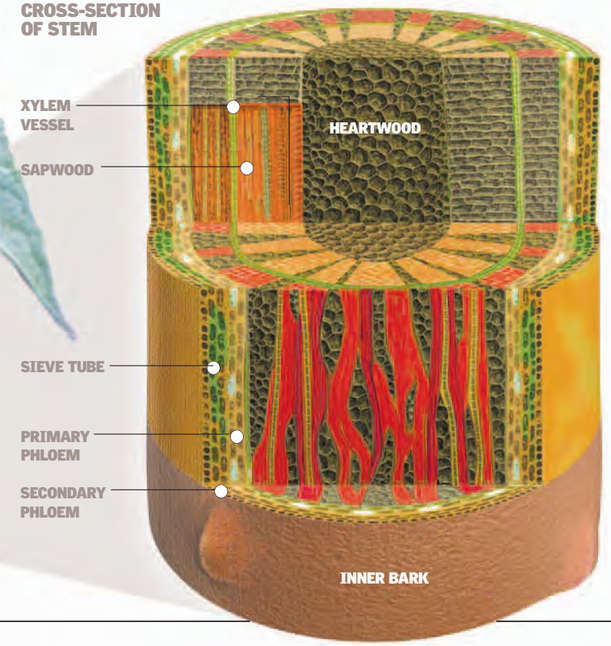
Circulation

Because the stem is the link between the roots, which absorb water and minerals, and the leaves, which produce food, the stem's veined tissues are connected to the roots and leaves. It functions as a transport system for interchanging substances. The stem and its branches hold the leaves up to receive light and support the plant's flowers and fruit. Some stems have cells with chlorophyll that carry out photosynthesis; others have specialized cells for storing starch and other nutrients.

MOVEMENT THROUGH THE STEM
In plants, sugar and other organic molecules are transported through the phloem, which moves the sap. The molecules are transported through sieve tubes.



CROSS-SECTION OF STEM



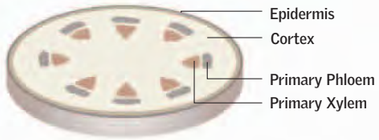
Wooden Heart

Every year a tree thickens its trunk through the production of growth rings, a process called secondary growth. Each new ring is different from the ring that grew the year before. This happens because the wood produced over the course of a year varies in its composition and in the time it takes to form a ring. Trees are the largest producers of wood, which can be processed as hand-cut wood, logs, or sawed lumber—the most common form in the industry. To calculate a tree's age scientists study its growth rings.

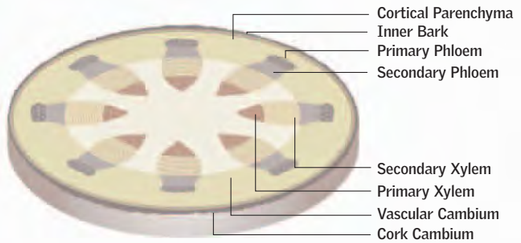
Secondary Growth

Secondary growth takes place in the secondary meristems: the vascular cambium and the cork cambium. The vascular cambium is found between the xylem and the phloem at the end of the plant's primary growth zone. It produces secondary xylem toward the inside of the trunk and secondary phloem toward the outside.

1 Initiation
The layer of meristematic cells formed between the xylem and the phloem develops inside the base tissue until it grows all the way around, forming a cylinder.



2 Lengthening
The primary xylem and phloem form when the vascular cambium divides.

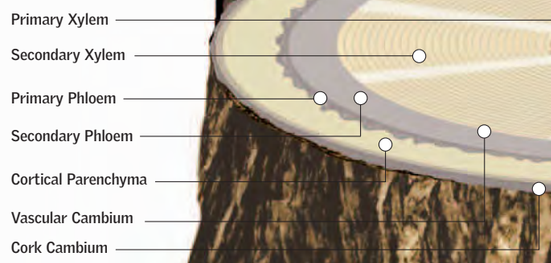


3 Termination
The veined cambium forms the primary and secondary vein tissues.

A Tree's Age

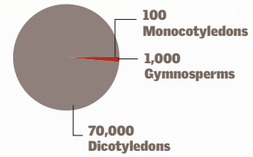
Dendrochronology is the study of the age of trees. The number of growth rings formed since a tree's birth establishes its age.

LABURNUM
Laburmun sp.



SPECIES

Most of the 70,000 known tree species are dicotyledons. However, the oldest trees (4,900-year-old bristlecone pines [*Pinus longaeva*]) and the tallest trees (360 foot [110 m] sequoias [*Sequoia sempervirens*]) are gymnosperms. The earliest trees known to paleobotany appeared during the Devonian Period.



TYPES OF WOOD

Wood comes from two main groups of trees:

Wood in angiosperms is the product of the activity of the cambium and the environmental conditions that exist during the wood's formation.

The wood of conifers (gymnosperms) tends to be simpler and more uniform than that of angiosperms. The woody tissue consists mainly of tracheids.

PHLOEM
The phloem transports the products of photosynthesis, mostly in the form of sucrose. This is its main function.

INNER BARK
is the youngest ring, because a new ring is created in each year's growth.

XYLEM
Its main function is to carry water and mineral salts from the roots to the leaves.

SAPWOOD
is the woody part of the trunk and consists of xylem tissue. It is pale in color and of variable thickness.

Rolled Logs
Not processed before use, they are often used in rural and traditional construction.

Hand-Hewn Wood
is chopped by hand with an ax. It is used in rural construction for rafters and posts, but it involves a considerable loss of wood.

Sawed Lumber
It is cut to specified dimensions, either manually or mechanically, in a sawmill. It is the type of wood most often used in construction.

Growth Springs Eternal

Some vascular (veined) plants, also called tracheophytes, are able to continue growing year after year. This is made possible by meristems, groups of stem cells that retain the ability to divide. There are two types of meristems: apical, which carry on the plant's primary growth, and lateral, which give rise to the tissues that increase the plant's girth. As the meristematic cells form new cells, the plant grows and renews its organs. Thanks to their growth buds, the plants maintain their vitality and strengthen their organs or replace them often. Because of this process, the renewed plants are able to increase their number of branches, flowers, and leaves.

Without Bracts
Some buds, such as those in plants of the cabbage family (Brassicaceae), are not covered by bracts. Instead, the vegetable's growth zone is covered by outer leaves.

INFRAPETIOLAR BUD
The axillary bud is joined to the petiole of a leaf. The growth of the leaf carries the bud outward. This often occurs in plants with inflorescences, or flowers that grow on branches.

SUPERPOSED BUD
The axillary bud is joined to the stem. As the cells of the internode multiply, they carry the axillary bud, which then appears to be inserted above the leaf.

Branching

Growth buds can be found at the end of the main axis (apical bud) or at the joint where the leaves meet the stem (lateral bud). Growth can take different forms, depending on the type of bud that predominates. If apical buds are more common, the branch growth is called monopodial. If lateral buds predominate, the branch growth is called sympodial. Conifers are an example of monopodial growth. Sympodial growth is widespread among dicotyledon herbs and is found in practically all monocotyledons.

PHYLLOTAXIS
is the name of the order of plants whose leaves are arranged along the nodes of the branches. Each node can have from one to several leaves.

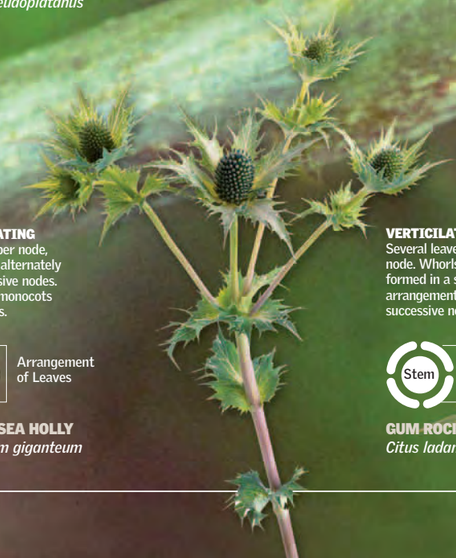
Awakening

Apical buds can remain dormant for long periods of time. With the right physiological and environmental conditions, they can awaken and unfold.

Leaf Shoots

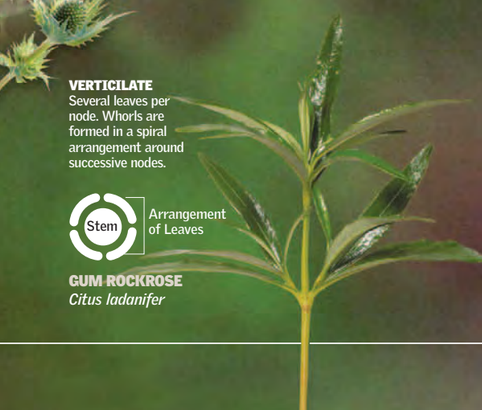
A lengthwise cross-section of a bud shows the curving and overlapping leaf sprouts that protect the bud's growth zone.

SYCAMORE MAPLE
Acer pseudoplatanus



ALTERNATING
One leaf per node, arranged alternately in successive nodes. Found in monocots and dicots.

GIANT SEA HOLLY
Eryngium giganteum



VERTICILATE
Several leaves per node. Whorls are formed in a spiral arrangement around successive nodes.

GUM ROCKROSE
Citus ladanifer

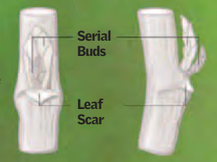
OPPOSITE
Two leaves per node. They are arranged perpendicularly to earlier and later nodes.

CLARY SAGE
Salvia sclarea

Lateral Buds

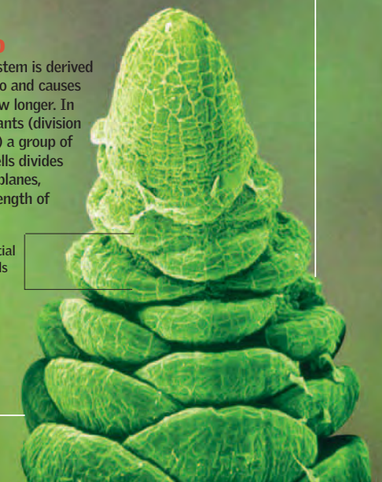
These buds occur on the side of the stem; typically, only one is located in the stem joint. In some cases many lateral buds are arranged in a series around a column (serial buds). They can also be arranged around the same crosswise line along the branch or stem (collateral buds).

Serial Buds
These buds are situated one above the other at the joint where the protective leaf meets the stem, forming a vertical file. The honeysuckle and the bougainvillea are examples of this type of bud.



Collateral, or Adjacent, Buds
are situated one on either side in the joint of the same leaf, forming a horizontal line. In garlic each clove is an axillary bud.

APICAL BUD
The apical meristem is derived from the embryo and causes the stem to grow longer. In seed-bearing plants (division Spermatophyta) a group of meristematic cells divides along different planes, increasing the length of the stem.



Energy Manufacturers

The main function of leaves is to carry out photosynthesis. Their shape is specialized to capture light energy and transform it into chemical energy. Their thinness minimizes their volume and maximizes their surface area that is exposed to the Sun. However, there are a great many variations on this basic theme, which have evolved in association with different types of weather conditions.

EDGES (MARGINS)
Species are distinguished by a wide variety of edges: smooth, jagged, and wavy.

PRIMARY VEINS
The products of photosynthesis circulate through the veins from the leaves to the rest of the body.

VEINS
Flowering plants (division Angiosperma) are often distinguished by the type of veins they have: parallel veins in monocots and branching veins in dicots.

RACHIS

LEAF STEM (PETIOLE)

***ACER* SP.**
This genus includes trees and bushes easily distinguishable by their opposite and lobed leaves.

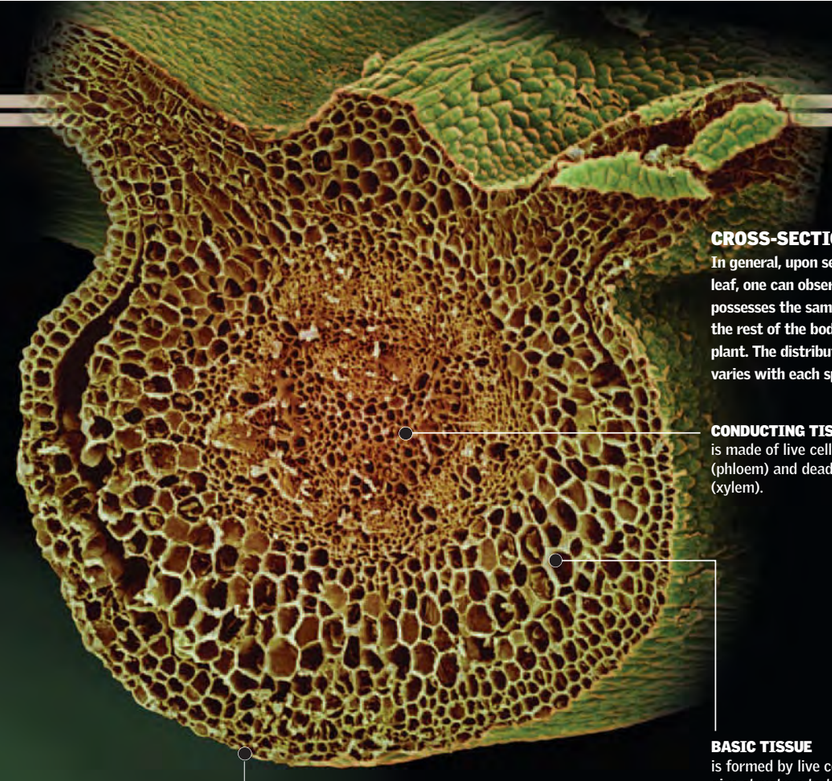
LEAF SURFACE
Colorful, usually green, with darker shades on the upper, or adaxial, side. The veins can be readily seen.

Simple Leaves

In most monocotyledon plants the leaf is undivided. In some cases it may have lobes or notches in its side, but these divisions do not reach all the way to the primary vein of the leaf.

Compound Leaves

When the leaf is divided from the primary vein, it forms separate leaflets. A compound leaf is called palmate when the leaflets are arranged like the fingers on a hand and pinnate when they grow from the sides of the leaf stem like the barbs of a feather.

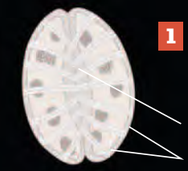


CROSS-SECTION
In general, upon sectioning a leaf, one can observe that it possesses the same tissues as the rest of the body of the plant. The distribution of tissues varies with each species.

CONDUCTING TISSUE
is made of live cells (phloem) and dead cells (xylem).

BASIC TISSUE
is formed by live cells that give structure to the leaf and usually contain some chloroplasts.

EPIDERMAL TISSUE
is composed of live cells. It surrounds all the parts of the leaf and the plant. It produces a substance that forms the cuticle.



1 The stomatic apparatus is closed. No air can enter or leave the leaf. This prevents excessive transpiration, which could damage the plant.

Thickened cell walls in the area of the pore

Cellulose Microfibers

2 The stomatic apparatus is open. The stomatic cells are swollen. As tension increases, the cellular form is modified and is able to exchange gases.

PLANTS AND THE ENVIRONMENT

The flow of carbon dioxide and water vapor between the plant and the environment is essential for the photosynthetic process. This exchange can be affected by internal or external factors, such as changes in light, temperature, or humidity. In response to these stimuli the stomas can open or close.

Change and Its Advantages

Conifers possess an interesting modification in their leaves. In these gymnosperms evolution directed the abrupt reduction of surface foliage area. This gave them an adaptive advantage over plants whose leaves have a large surface area: less resistance to wind and less transpiration in arid climates. In addition, they are able to avoid the excessive weight that would result from the accumulation of snow on large leaves.

VASCULAR BUNDLE
Formed by phloem and xylem

RESIN
functions to prevent freezing. It circulates through the resin ducts.

EPIDERMIS
Cells with thick walls and a thick cuticle

CONIFERS

Needle-shaped leaves are characteristic of conifers. They are usually oval or triangular. A hypodermis, which is enclosed by the epidermis, is broken only in the stomas.

TENDRILS

The leaves of climbing plants, such as the grapevine, have these adaptive modifications.

Functional Beauty

Flowers are not simply beautiful objects; they are also the place where the reproductive organs of angiosperms are located. Many are hermaphroditic, meaning that they contain both the male reproductive apparatus (the androecium) and the female (the gynoecium). The process of pollination is carried out through external agents, such as insects, birds, wind, and water. Following fertilization, flowers produce seeds in their ovaries. The floral parts are arranged in circular or spiral patterns.

Classification

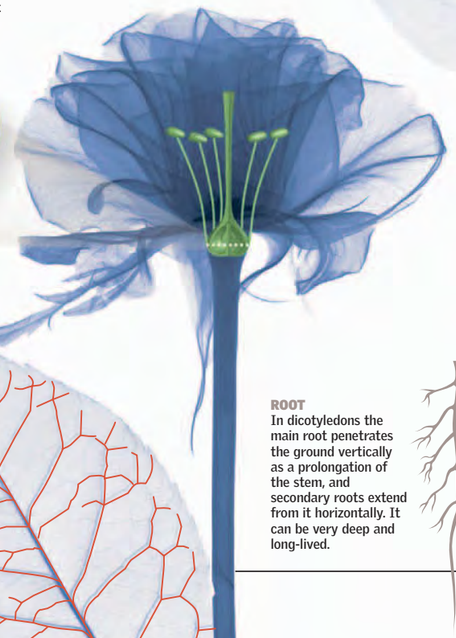
Plants with flowers are classified as dicotyledons or monocotyledons. The first group has seeds with two cotyledons, and the second has seeds with only one. Each represents a different evolutionary line. They are differentiated by the structure of their organs. The cotyledon contains nutrients that the embryo utilizes during its growth until its true leaves appear. When a seed germinates, the first thing that appears is the root. In monocotyledons the stem and the radicle are protected by a membrane; the dicotyledons lack this protection, and the stem pushes itself through the soil.

Dicotyledons

In this class of plants each whorl of the flower is arranged in groups of four or five parts. In dicotyledons the sepal is small and green, the petals are large and colorful, and the leaves are wide. The vascular ducts are cylindrical.

FLORAL DIAGRAM

OVARY
The ovary is found in the receptacle at the base of the gynoecium, inside the carpels. The pollen tube extends into the ovary and penetrates the ovule.



LEAVES
In dicotyledons, leaves have various forms, and they contain a network of veins that connect with a primary vein.

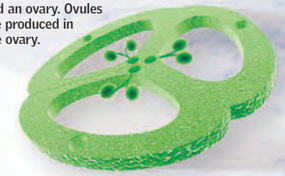
ROOT
In dicotyledons the main root penetrates the ground vertically as a prolongation of the stem, and secondary roots extend from it horizontally. It can be very deep and long-lived.

Monocotyledons

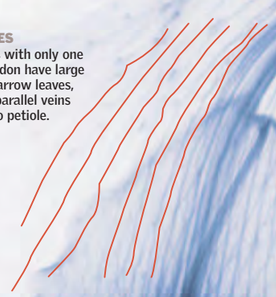
Each whorl of these flowers contains three parts, and their sepals and petals are generally not differentiated from one another. The majority are herbaceous plants with scattered vascular conduits. They are the most evolved species of angiosperms.

FLORAL DIAGRAM

CARPEL
The carpel consists of modified leaves that together form the gynoecium. It contains a stigma, a style, and an ovary. Ovules are produced in the ovary.



LEAVES
Plants with only one cotyledon have large and narrow leaves, with parallel veins and no petiole.



ROOT
In monocotyledons all the roots branch from the same point, forming a kind of dense hair. They are generally superficial and short-lived.

Androecium
The male reproductive system. It is formed by a group of stamens, each of which consists of an anther supported by a filament. The base may contain glands that produce nectar.

ANTHER
A sac where grains of pollen (the male gametes) are produced

FILAMENT
Its function is to sustain the anther.

Gynoecium
The female reproductive system. It is formed by carpels and includes the ovary, ovules, style, and stigma.

STIGMA
It can be simple or divided. It secretes a sticky liquid that captures the pollen. Some are also covered with hair.

STYLE
Some styles are solid, others hollow. Their number depends on the number of carpels. The pollen tube grows through the style. In corn the tube can reach a length of 15 inches (40 cm).

OVARY
The ovary is found in the receptacle in the base of the gynoecium, inside the carpels. The pollen tube, which conducts the pollen to the ovule, extends to the ovary.

Whorls

Most flowers have four whorls. In a typical flower the outermost whorl is the calyx, followed by the corolla, the androecium (which can have two parts), and the gynoecium. When a flower has all four whorls, it is considered complete; it is incomplete when it lacks at least one of them. Plants that have an androecium and a gynoecium, but in separate flowers, are called monoecious. If the flower lacks a sepal and petals, it is said to be naked.

250,000

THE NUMBER OF KNOWN SPECIES OF ANGIOSPERM PLANTS, THOUGH ONLY 1,000 SPECIES HAVE ECONOMIC IMPORTANCE. ABOUT TWO THIRDS OF THESE SPECIES ARE NATIVE TO THE TROPICS.

COROLLA
A grouping of petals. If its parts are separated, they are simply called petals; if they are united, the plant is described as gamopetalous.

PETAL
It typically has a showy color to attract pollinating insects or other animals.

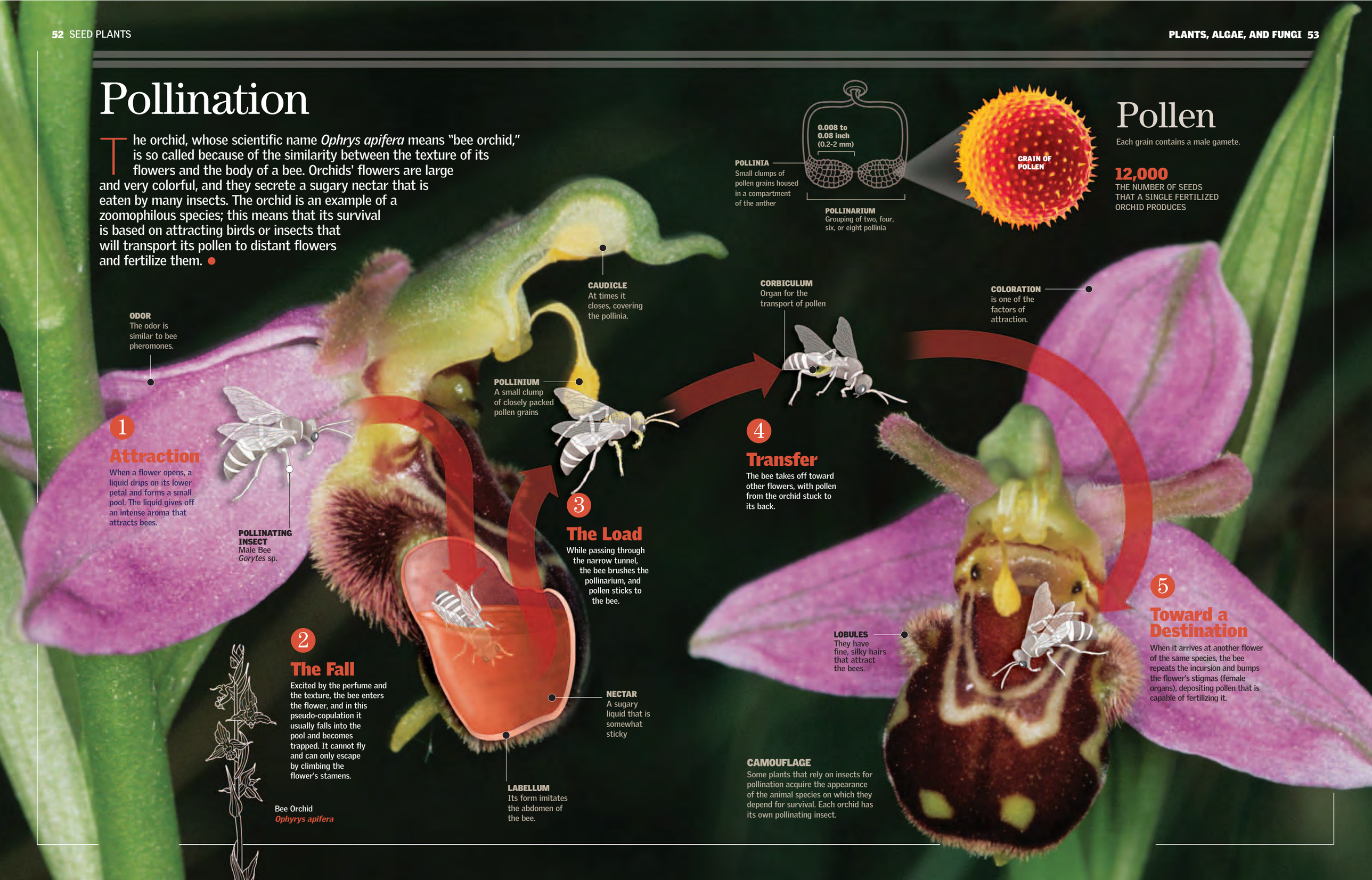
CALYX
The grouping of sepals that protects the other parts of the flower. Together with the corolla it forms the perianth. The sepals may be separate or united; in the latter case the plant is called gamosepalous.

SEPAL
Each of the modified leaves that protect the flower in its first stage of development. They also prevent insects from gaining access to the nectar without completing their pollinating function. Sepals are usually green.

TEPAL
In monocotyledonous plants the petals and sepals are usually the same. In this case they are called tepals, and the group of tepals is called a perianth.

Pollination

The orchid, whose scientific name *Ophrys apifera* means "bee orchid," is so called because of the similarity between the texture of its flowers and the body of a bee. Orchids' flowers are large and very colorful, and they secrete a sugary nectar that is eaten by many insects. The orchid is an example of a zoomophilous species; this means that its survival is based on attracting birds or insects that will transport its pollen to distant flowers and fertilize them.



Pollen

Each grain contains a male gamete.

12,000
THE NUMBER OF SEEDS THAT A SINGLE FERTILIZED ORCHID PRODUCES

1 Attraction

When a flower opens, a liquid drips on its lower petal and forms a small pool. The liquid gives off an intense aroma that attracts bees.

2 The Fall

Excited by the perfume and the texture, the bee enters the flower, and in this pseudo-copulation it usually falls into the pool and becomes trapped. It cannot fly and can only escape by climbing the flower's stamens.

3 The Load

While passing through the narrow tunnel, the bee brushes the pollinarium, and pollen sticks to the bee.

4 Transfer

The bee takes off toward other flowers, with pollen from the orchid stuck to its back.

5 Toward a Destination

When it arrives at another flower of the same species, the bee repeats the incursion and bumps the flower's stigmas (female organs), depositing pollen that is capable of fertilizing it.

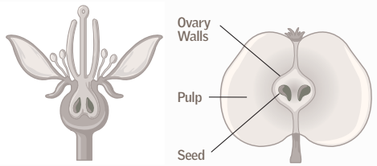
CAMOUFLAGE
Some plants that rely on insects for pollination acquire the appearance of the animal species on which they depend for survival. Each orchid has its own pollinating insect.

Bearing Fruit

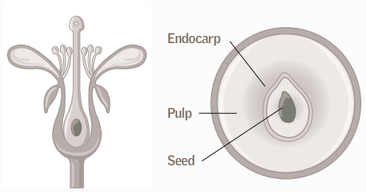
Once the flower is fertilized, its ovary matures and develops, first to protect the seed forming within it and then to disperse the seed. The stigmas and anthers wither, and the ovary transforms into fruit. Its wall forms the cover, or pericarp. Fruits and seeds are of great economic importance because of their key role in human nutrition. The endosperms of some seeds are rich in starch, proteins, fats, and oils.

Simple Fruits

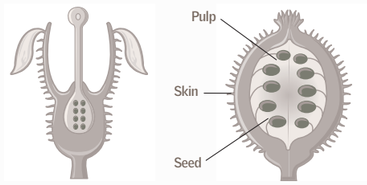
come from a single flower. They may contain one or more seeds and be dry or fleshy. Among them are drupes, berries, and pomes.



A POMES
are fleshy fruits that come from epigynous flowers, or flowers whose enclosed ovaries lie below the place where the other parts of the flower are attached. The floral receptacle thickens and forms an edible mesicarp. Apples are one example.



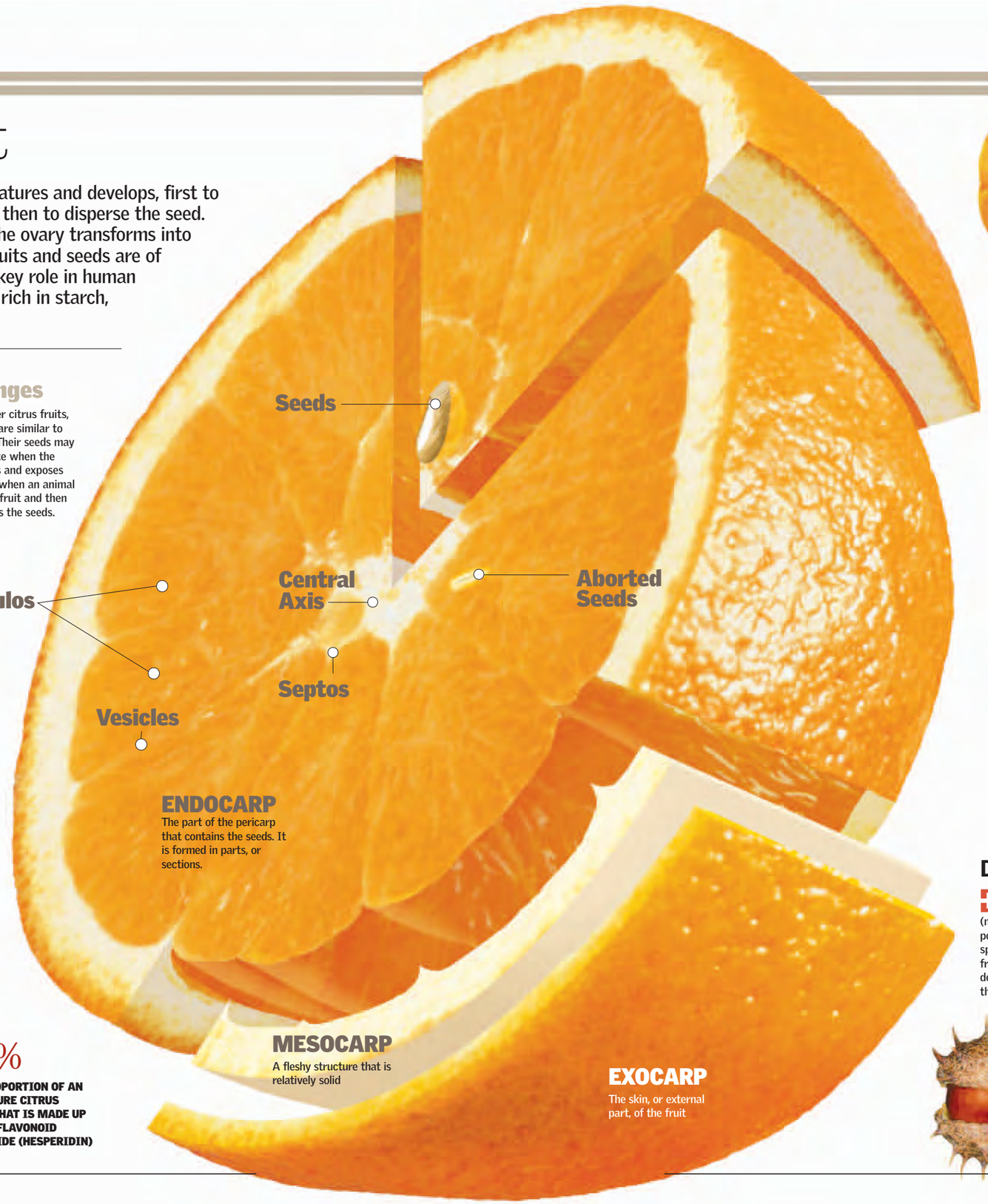
B DRUPES
are fleshy fruits, leathery or fibrous, which are surrounded by a woody endocarp with a seed in its interior. They are generally derived from hypogynous flowers—flowers whose ovaries lie above the point where the other flower parts are attached. An example is the peach.



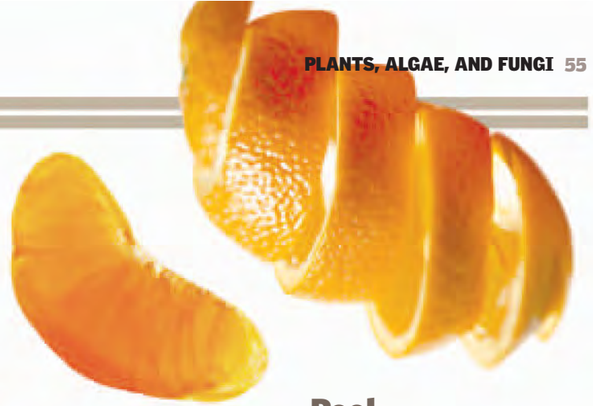
C BERRIES
When they mature, berries generally have a bright color and a fleshy or juicy mesocarp. They come from either epigynous or hypogynous flowers. The grape is an example.

Oranges

Like other citrus fruits, oranges are similar to berries. Their seeds may propagate when the fruit rots and exposes them or when an animal eats the fruit and then defecates the seeds.



14%
THE PROPORTION OF AN IMMATURE CITRUS FRUIT THAT IS MADE UP OF THE FLAVONOID GLYCOSIDE (HESPERIDIN)



Section
A sac that fills with juices (reserves of water and sugar) produced by the ovary walls

Peel
It consists of the mesocarp and exocarp of the fruit. It is soft and secretes oils and acids. However, in the case of a nut, its hard "peel" is its endocarp.

Multiple Fruits

are those that develop from the carpels of more than one flower, in a condensed inflorescence. When they mature, they are fleshy. An example is the fig.

BLACKBERRY
In this aggregate fruit, each berry is a fruit.

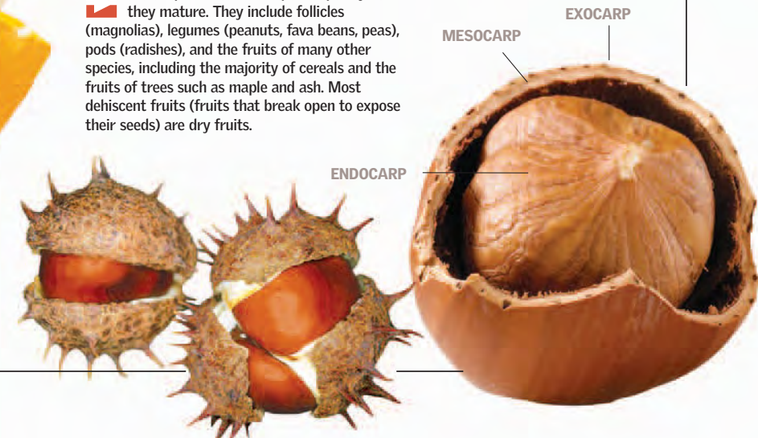
FIG
Condensed fruit

A AGGREGATE FRUIT
The fruit is made of numerous drupelets that grow together.

B SYCONIUM
The fruit axis dilates and forms a concave receptacle with the shape of a cup or bottle.

Dry Fruits

are simple fruits whose pericarps dry as they mature. They include follicles (magnolias), legumes (peanuts, fava beans, peas), pods (radishes), and the fruits of many other species, including the majority of cereals and the fruits of trees such as maple and ash. Most dehiscent fruits (fruits that break open to expose their seeds) are dry fruits.



Conifers

Are effectively the most representative of the gymnosperms, a group of plants with seeds but not flowers. Through the fossil record it is known that conifers have existed for more than 390 million years. Their leaves are usually needle-shaped and perennial. They are woody plants that reproduce by means of seeds that contain tissues and an embryo that grows until it becomes an adult plant.

YOUNG LEAVES
are covered by a protective capsule.

FEMALE CONE
Small and light, it is likely to be pollinated as soon as it appears.

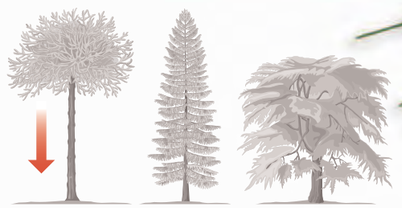
LEAVES
Grouped in sets of two, they have elongated shapes. They carry out photosynthesis.

CONES
The male and female cones are generally not located on the same branch.

MATURE CONE
Three years after the cone appears, its seeds are ready to disseminate.

Classification

The name "conifer" is sometimes erroneously believed to derive from pine trees' conical shape. In reality, there are other forms of coniferous plants.



ARAUCARIA *Araucariaceae*

PINE *Pinaceae*

CEDAR *Taxodiaceae*

Good Wood

The great majority of conifers are evergreens, although some, such as larches (tamarac), are deciduous. Conifers are the tallest and most long-lived trees, and they provide most of the wood used in industry. Most conifers form new shoots during the summer. They produce a resinous substance that protects them from freezing during winter. This adaptation permits vital nutrients to continue to circulate through their vascular systems, even in very cold weather.

14° F (-10° C)
OR LESS: TYPICAL AVERAGE
January temperature across the extensive coniferous forests of the Northern Hemisphere.

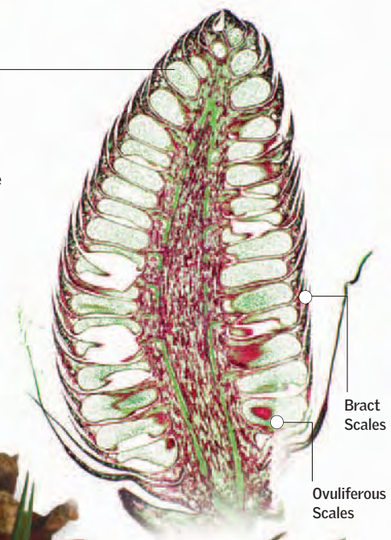
LEAFLET

SCALE

DISPERSION
The ovuliferous scales generate a greenish gelatin containing the female gametes. The gametes are freed when the sac that contains them opens. A forest fire can promote reproduction by causing the sac to open.

Pine Cones

The female cone contains ovules that are situated among its ovuliferous scales. The cones are woody and are usually found in the upper branches of the tree. The male cones are not woody and are usually found in the lower branches. When the ovules of a female cone are pollinated, the resulting seeds need about three years to mature inside the cone. Mature ovules are popularly called pine nuts.



CLOSED

OPEN

Pine Nuts

Pine nuts have long been used with honey and sugar to make pastries. When summer arrives, harvested pine cones are placed in the sun, which causes them to open. The pine nuts are then shaken loose from their cones and gathered. In traditional processing the pine nuts are soaked in water to remove their outer covering, which floats to the surface. The pine nuts are then run between two closely spaced mechanical rollers to crack their inner shells. Finally, the pine-nut meat is separated from the shell by hand.

Rare and Useful Plants

VENUS FLYTRAP
The most common carnivorous plant. It is considered to be an active trap.

TRAPPERS 60-61
HANGING FROM OTHER PLANTS 62-63
DANGEROUS RELATIONSHIPS 64-65
INFLORESCENCES 66-67
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FROM TREE TO PAPER 76-77
HEALING PLANTS 78-79

How does a carnivorous plant hunt an insect, and what type of traps does it use? Why do many plants have thorns or secrete venomous juices, while others grow on the trunks of trees or on the side of rocks? The truth is that in order to survive in harsh environments, such as places that are extremely dry or cold or places with nutrient-poor soil or herbivorous animals, plants have had to become very strong and develop a number of strategies for survival, which we will tell you about in this chapter. You will also find detailed information about where the paper that we use daily comes from, as well as learn about the production of tomatoes and olive oil, essential elements in the human diet. ●

Trappers

These carnivorous plants are the most exotic in the entire plant kingdom. Their name is associated with their ability to capture insects and digest them. What do they get from these tiny animals? They get substances rich in nitrogen, which is usually absent from the soil where they grow. By eating insects, they are able to compensate for this nitrogen deficiency because the bodies of the arthropods they catch have amino acids and other nutrients that contain nitrogen. ●

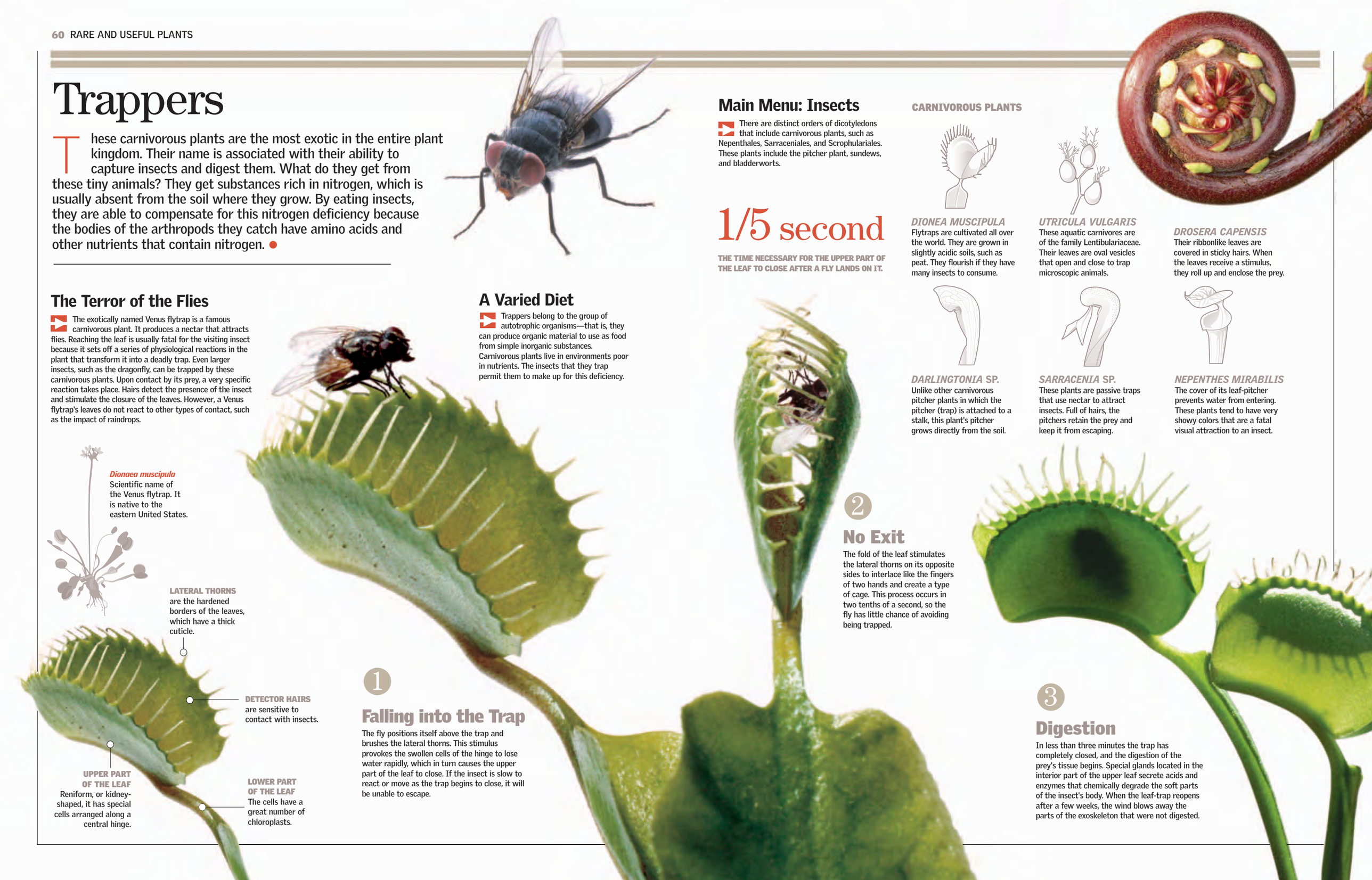
The Terror of the Flies

The exotically named Venus flytrap is a famous carnivorous plant. It produces a nectar that attracts flies. Reaching the leaf is usually fatal for the visiting insect because it sets off a series of physiological reactions in the plant that transform it into a deadly trap. Even larger insects, such as the dragonfly, can be trapped by these carnivorous plants. Upon contact by its prey, a very specific reaction takes place. Hairs detect the presence of the insect and stimulate the closure of the leaves. However, a Venus flytrap's leaves do not react to other types of contact, such as the impact of raindrops.

Dionaea muscipula
Scientific name of the Venus flytrap. It is native to the eastern United States.

A Varied Diet

Trappers belong to the group of autotrophic organisms—that is, they can produce organic material to use as food from simple inorganic substances. Carnivorous plants live in environments poor in nutrients. The insects that they trap permit them to make up for this deficiency.



1 Falling into the Trap

The fly positions itself above the trap and brushes the lateral thorns. This stimulus provokes the swollen cells of the hinge to lose water rapidly, which in turn causes the upper part of the leaf to close. If the insect is slow to react or move as the trap begins to close, it will be unable to escape.

2 No Exit

The fold of the leaf stimulates the lateral thorns on its opposite sides to interlace like the fingers of two hands and create a type of cage. This process occurs in two tenths of a second, so the fly has little chance of avoiding being trapped.

3 Digestion

In less than three minutes the trap has completely closed, and the digestion of the prey's tissue begins. Special glands located in the interior part of the upper leaf secrete acids and enzymes that chemically degrade the soft parts of the insect's body. When the leaf-trap reopens after a few weeks, the wind blows away the parts of the exoskeleton that were not digested.

Main Menu: Insects

There are distinct orders of dicotyledons that include carnivorous plants, such as Nepenthales, Sarraceniales, and Scrophulariales. These plants include the pitcher plant, sundews, and bladderworts.

1/5 second

THE TIME NECESSARY FOR THE UPPER PART OF THE LEAF TO CLOSE AFTER A FLY LANDS ON IT.

CARNIVOROUS PLANTS

DIONEA MUSCIPULA
Flytraps are cultivated all over the world. They are grown in slightly acidic soils, such as peat. They flourish if they have many insects to consume.

UTRICULA VULGARIS
These aquatic carnivores are of the family Lentibulariaceae. Their leaves are oval vesicles that open and close to trap microscopic animals.

DROSERA CAPENSIS
Their ribbonlike leaves are covered in sticky hairs. When the leaves receive a stimulus, they roll up and enclose the prey.

***DARLINGTONIA* SP.**
Unlike other carnivorous pitcher plants in which the pitcher (trap) is attached to a stalk, this plant's pitcher grows directly from the soil.

***SARRACENIA* SP.**
These plants are passive traps that use nectar to attract insects. Full of hairs, the pitchers retain the prey and keep it from escaping.

NEPENTHES MIRABILIS
The cover of its leaf-pitcher prevents water from entering. These plants tend to have very showy colors that are a fatal visual attraction to an insect.

Hanging from Other Plants

The epiphytes are a very interesting group of plants. They grow on living or dead tree trunks, surfaces of rocks, wall nooks, and even utility poles and wires. Mosses, ferns, orchids, and bromeliads are among the best-known epiphytes. Bromeliads are native to the tropical and humid regions of the Western Hemisphere. They are of special interest because they exhibit evolutionary adaptations that favored their ability to live without contact with soil. They therefore have novel strategies for obtaining the water, minerals, carbon dioxide, and light that they need to survive.

MEDUSA'S HEAD
Tillandsia caput medusae

LEAVES
Few and leathery. They are covered in absorbent hairs.

FRUITS
Fusiform. They measure 1.5 inches (4 cm) in length and barely 0.15 inch (4 mm) in diameter. They contain feathery seeds that disperse with the wind.

SPECIAL SIGNS
These plants are recognized for their bulbs, which have the shape of a small rose, and for their triangular leaves, which are densely covered by hairs. The purple lilac color on their petals is also very characteristic.

Inflorescences in the Form of a Spike

Special Leaves

The best-known function of these plants' leaves is to absorb water. In addition, at night they incorporate carbon dioxide and fix it into organic acids. This strategy diminishes their water loss through transpiration during the day through the opening of the stomas for gas exchange. When sunlight is available, photosynthesis takes places. The plants are able to manufacture carbohydrates without opening their stomas, because they can use the carbon dioxide that they took in during the night.

A Different Lifestyle

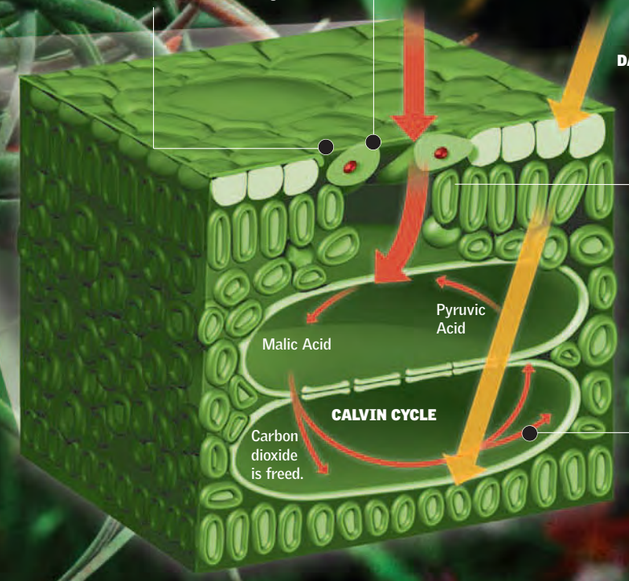
Bromeliads' roots do not absorb water. Their hard leaves can capture water and nutrients from the air. Using a sticky substance, they usually attach themselves to the branches of trees, where they can have access to sunlight. These traits make it possible for the them to subsist in their natural environment.

ROOTS
They are in charge of attaching the plant to the substrate, but they do not absorb water or minerals.

BULB
The stalk is very short or nonexistent. They are herbs that form rosette-shaped bulbs with their leaves.

FLOWER
It has the form of a tube, and its color ranges from red to violet. There may be up to 14 flowers in each inflorescence.

FROM THE NEW WORLD
The common origin of the bromeliads is Mexico and the countries of Central and South America. Today bromeliads are cultivated all over the world.



Dangerous Relationships

During their life cycle some plants become a true danger to other plants. There are groups of epiphytes that, in their quest to reach the soil and turn into trees, are capable of strangling and killing the tree on which they begin to grow. Additionally, some plants behave like parasites or semi-parasites. When the seeds of these plants germinate and their embryos have used up their energy reserves, they continue to grow because they obtain food from their hosts.

Deadly Embrace

The genus *Ficus* has some lethal plants among its members. The epiphyte species of the genus, during its young stage, can strangulate and kill the tree on which it supports itself. In this way it can reach the sunlight, which is typically scarce on the forest floor. For example, the strangler fig *(Ficus nymphaeifolia)*, which reaches 23 to 115 feet (7-35 m) in height, produces seeds that can germinate on the branches of another tree. This permits it to grow to a tree of great size that develops an extended crown of long, strong branches. Its roots descend to the ground along the trunk of the host tree and fuse together, forming a thick lattice. The distinct varieties of trees of the *Ficus* genus are characteristic of the rainforests of the intertropical zone. Many are of American origin.

SICONO
This type of infructescence is a pyriform receptacle, hollow and with an apical opening. In its internal walls small berries, commonly called seeds, are found.

Mistletoe

It has chlorophyll but no roots. It parasitizes the branches of a tree, disguising itself as just another branch. Mistletoe appears in places like semi-abandoned olive groves. It is native to humid zones and mountainous areas. The parasite debilitates the host and makes it more vulnerable to insect attacks. The host trees may be killed by the mistletoe or by diseases that attack the tree in its weakened state.

EUROPEAN MISTLETOE
The birds that eat mistletoe fruits disperse the seeds, which are sticky and attach to other trees.

IMPRISONED
The aerial roots of the straggler fig move toward the ground, perhaps as the result of geotropism. As the roots grow, they merge together and imprison the host tree.

DODDER
It forms a genus, *Cuscuta*, of between 100 and 170 species of parasitic plants that are yellow, orange, or red.

Like a Vampire

Dodder, a plant of the *Cuscuta* genus, parasitizes its host by inserting itself into the host's vascular system and sucking out its nutrients. These parasites do not contain chlorophyll, and their leaves appear as small scales. Dodder germinates on the ground. It then grows around the stalk of a host plant and inserts small rootlike projections, called haustoria, into the stalk. As dodder grows, its many filamentous stems can look like spaghetti. Dodder kills herbaceous plants and debilitates woody ones. It is usually considered a pest because of the economic losses it produces in fodder plants such as alfalfa.

WITHOUT CLOROPHYLL
The stalk and the leaves of these plants do not have chlorophyll; in addition, their leaves are very small.

Evolutionary Pressure

The evolution of plants, like that of living beings in general, has favored the rise of the secondary adaptations shown here. These adaptations have benefited certain species with notable characteristics, such as parasitism. The distinctive trait in these plants is the absence of conductive vessels.

1
Upon coming into contact with its host, the vine begins to develop haustoria. They will grow and penetrate the stalk of the host to reach its vascular tissues (xylem and phloem).

2
After germinating, dodder's stems climb and coil around the stalk of the host until the haustoria develop.

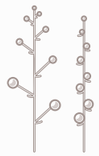
3
The products of photosynthesis circulate through the phloem, where they are accessed by the haustoria.

Inflorescences

Inflorescences consist of clusters of flowers on a branch or system of branches. They can be simple or complex. They are simple when a flower forms on the main axis in the axil of each bract. They are complex when a partial inflorescence is born in the axil of the bract that also carries bracteoles or prophylls. Simple inflorescences include racemes, spikes, panicles, catkins, corymbs, and heads. Complex inflorescences include double racemes, double spikes, and double umbels. ●

Types of Inflorescences

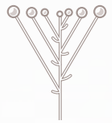
Most inflorescences correspond to branching in which the axis grows in an indeterminate manner, and the flowers open in order from the base of the axis toward the apical meristem. There are also determinate inflorescences, in which the end of the axis bears the first flower, and flowers farthest from it open last.



RACEME
The flowers develop on short stalks, called pedicels, along an unbranched axis.

SPIKE
The flowers form directly from the stem instead of from pedicels.

HEAD
The flowers sit on a broad, shortened axis.



CORYMB
The pedicels are of varying lengths.

CATKIN
Similar to a hanging spike, its flowers are entirely male or female.

UMBEL
A group of pedicels spread from the end of the flower stalk.

COMPOUND RACEME
The flower stalks are branched.

SPADIX
It features a spike with a fleshy axis and dioecious flowers.

COMPOUND UMBEL
This form is more common than the simple umbel.

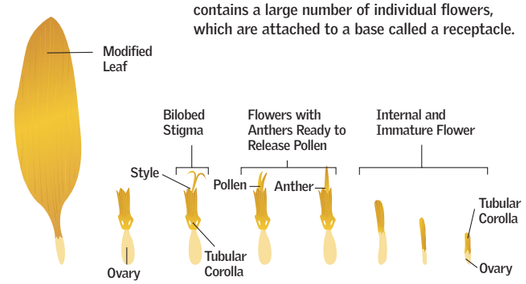
Sunflower

Its inflorescence is a head made of two types of flowers: peripheral florets, which are rayed and unisexual, and disk florets, which are tubular and hermaphroditic.

19 feet (6m)
IS THE MAXIMUM HEIGHT OF SUNFLOWERS. THEIR AVERAGE HEIGHT IS 10 FEET (3 M).

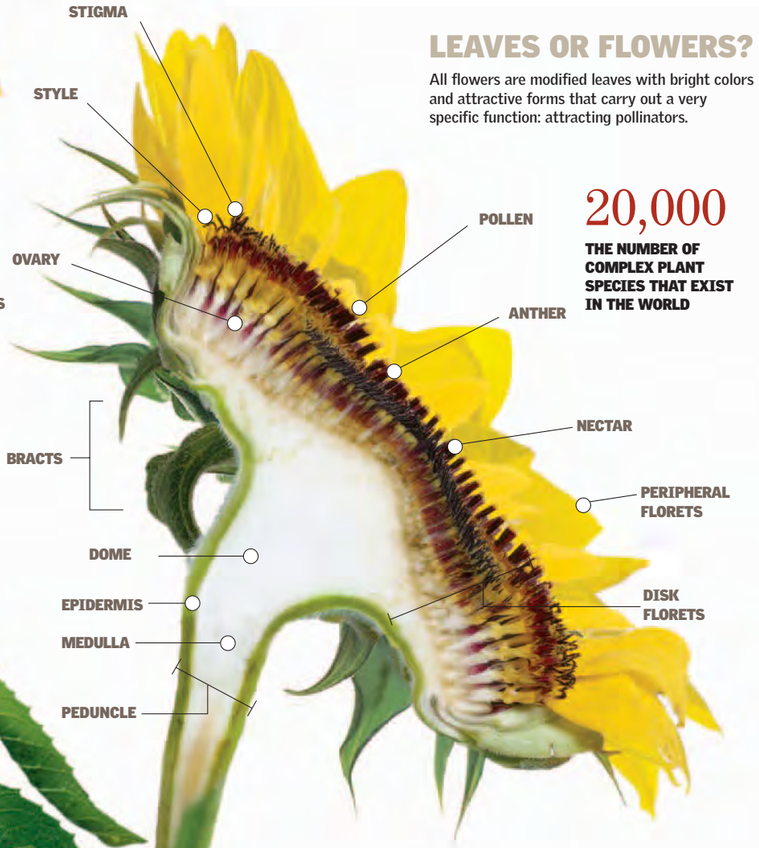
DAISY

The daisy is a composite flower. As with the sunflower, what appears to be a single flower is, in fact, an inflorescence called a head. The head contains a large number of individual flowers, which are attached to a base called a receptacle.



LEAVES OR FLOWERS?

All flowers are modified leaves with bright colors and attractive forms that carry out a very specific function: attracting pollinators.



20,000
THE NUMBER OF COMPLEX PLANT SPECIES THAT EXIST IN THE WORLD

Between Wind and Sand

The family Cactaceae has 300 genera and thousands of plant species that inhabit predominantly hot and dry places. Cacti are the best known of these species. They have spines that developed to minimize water loss and to provide protection against herbivores. Although cacti originated in the Western Hemisphere, they have spread to other parts of the world. Cacti produce nectar, which plays an important role in pollination by attracting insects and birds to their flowers.

Distribution

Cacti are found in deserts or very dry climates. They have also adapted to the dry and warm climates of Australia, the Mediterranean, and East Africa.

2,000 species
OF PLANTS MAKE UP THE FAMILY CACTACEAE.

THEY RANGE FROM CANADA ALL THE WAY TO SOUTH AMERICA.

Echinopsis pentlandi

FRUIT
Generally fleshy berries. In some cases, however, the fruit is dry.

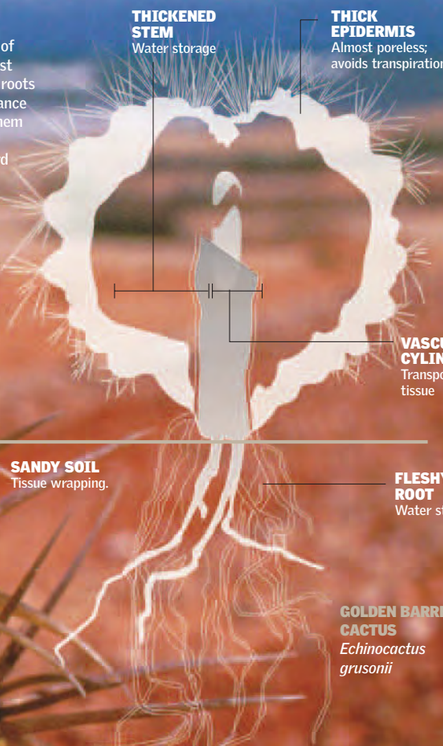
AREOLE
Axil bud that generates a very short branching of spines

CLADODE
Photosynthetic stem, often succulent, that has the ability to store water

ADAPTING TO THE ENVIRONMENT

One of the main characteristics of Cactaceae is their ability to resist drought by storing water. Their roots usually extend only a short distance into the ground, which allows them to better absorb occasional rainfall. Some roots grow toward the surface in order to collect dew. Their skin is covered with wax, which makes it tough and waterproof and helps prevent water loss.

CRASSULACEAN ACID METABOLISM (CAM)
Carbon dioxide is taken in at night and stored as organic acids. The plant is therefore able to avoid water loss by closing its stomas during the day, when it carries out photosynthesis.



GOLDEN BARREL CACTUS
Echinocactus grusonii

LEAVES
In place of simple and alternate leaves, they have thorns, which prevent water loss through transpiration and are a defense against attacks from animals.

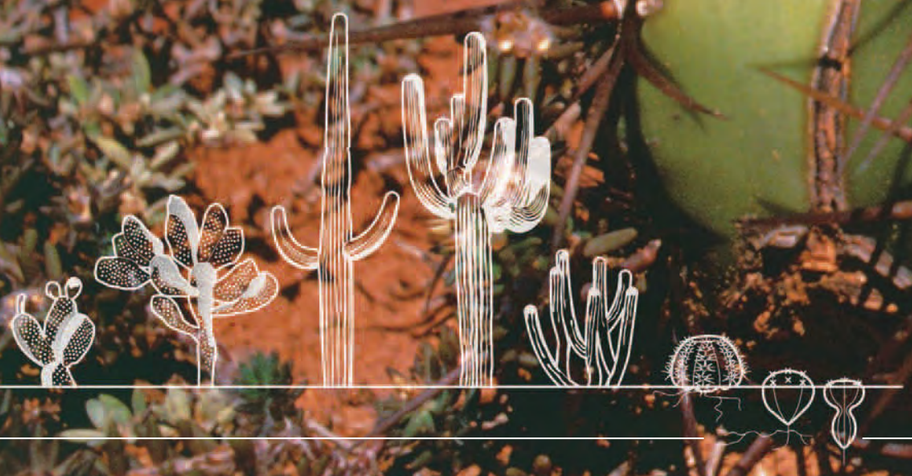
STEM
It is succulent and stores a large quantity of water. It contains chlorophyll and is where photosynthesis takes place.

Cactaceae Stems

Green
In the absence of green leaves, photosynthesis takes place in the stem.

Disguised
Epiphyllum cacti do not have leaves, so the stems perform their function.

Accordion
They are curvy and expand when they take in water.



Healing or Harmful?

Poisonous plants are the type that no one wants in the garden. Although some plants have healing properties, others have substances that, when they enter the body, provoke noxious reactions that cause injury or even death. The most infamous of these plants is hemlock, which can also be used medicinally. The primary active components of poisonous plants are alkaloids. One of the most potent poisons from plants is ricin: 0.35 ounce (1 mg) is enough to kill a person. ●

A Matter of Quantity

Poison is a substance that produces illness or tissue lesions or that interrupts natural vital processes when it comes into contact with the human organism. Dosage is a key factor for a substance to act as a poison. The same substance that can produce death in an organism can, in smaller concentrations, act as a medicine and provide relief from certain types of suffering.

Hemlock Water Dropwort
Oenanthe crocata

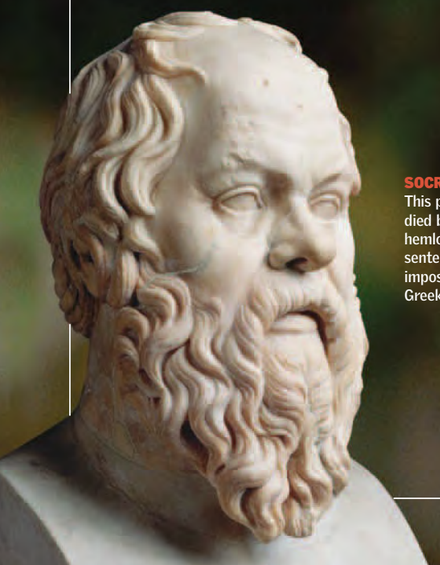
A plant belonging to the Umbelliferae family that is considered toxic because of its narcotic effects. However, it can also be medically prescribed to treat disorders such as epilepsy.

Poison Hemlock
Conium maculatum

HEIGHT
It can grow to a height of 6.5 feet (2 m).

Poison Hemlock

Also known as *Conium maculatum*, this herbaceous plant belongs to the Umbelliferae family. It has a hollow, striated stem, with purple spots at its base. Though poisonous, it has been used to calm strong pains and headaches. Poison hemlock has a characteristic offensive, urinelike odor. The active component in hemlock is coniine, an alkaloid that has neurotoxic effects.



SOCRATES
This philosopher died by drinking hemlock, a sentence imposed by the Greek court.

1. BURNING
Intoxication produces a dry mouth, dilated pupils (mydriasis), and nausea.

2. PARALYSIS
The legs weaken, the muscles become paralyzed, and respiratory failure and asphyxia take place.

3. DEATH
The subject remains conscious until the moment of death.

Other Poisonous Plants

Several cultivated and wild plants have active ingredients that have various levels of toxicity for people and animals. The castor bean *(Ricinus communis)* contains ricin, and chewing two of its seeds can be fatal for a child. *Digitalis* contains substances that can cause a heart attack. Other common poisonous plants, such as oleanders, provoke diarrhea, nausea, and other symptoms if their flowers or fruits are eaten.

Poison Ivy
Toxicodendron radicans

Poison Ivy

is a low vine that grows along the ground and often climbs walls, tree trunks, and bushes. It has bright green leaves that have an oily toxin, which causes light to severe allergic reactions. The symptoms can appear between one and three days after having touched the plant.

HEIGHT
It can grow to a height of 10 feet (3 m).

IDENTIFICATION
In winter the plant has no leaves but greenish white berries. In the summer the berries are green; they are red in the spring and can be yellow in early autumn.

10%
OF VEGETABLE SPECIES
have alkaloids, compounds formed with nitrogen.

Belladonna (Deadly Nightshade)

has three alkaloids that are considered poisonous: hyoscine, scopolamine, and atropine. These substances affect the autonomous nervous system, which regulates breathing and cardiac rhythm. In medicine atropine in low dosages decreases the intensity of intestinal contractions.

Belladonna
Atropa belladonna

HEIGHT
It grows to a height of 5 feet (1.5 m).

WAR FLOWER
It is said that belladonna was used to poison Mark Antony's troops during the Parthian wars.

Tomato Factories

The colonization of America brought about the discovery of an extraordinary variety of plants that have been used as food for a long time. An important example is the tomato, which is consumed globally. The cultivation of the tomato has reached marked levels of technological complexity that help address problems of infestation and adverse environmental conditions, as well as make it possible to grow tomatoes without using soil. ●

Tomato
Solanum lycopersicum

Traditional Cultivation

In gardens, tomato plants are grown in accordance with their annual growth cycle, using adequate soil and pest control.

Planting	End of Winter
Harvesting	Beginning of Summer

5.5 pounds (2.5 kg)
THE AVERAGE WEIGHT OF TOMATOES A PLANT CAN PRODUCE IN ONE YEAR

GREENHOUSE
Seedlings grow protected from frosts.

FERTILIZER
provides the soil with nutrients.

IRRIGATION
Every plant requires more than 0.5 gallon (2 l) of water every week as it grows.

GOOD NEIGHBORS
Raising carrot and cabbage crops in the same garden aids the development of tomatoes.

6 to 8 inches (15-20 cm)

TRANSPLANT
The seedling can be transplanted when it has three or four real leaves.

STAKES
help the plants to grow and remain upright.

NETTLES
discourage insects that destroy tomatoes.

SANDY LOAM SOIL
allows for the best development of tomatoes.

LEVEL A
has nutrients that are essential to the plant.

Water Absorption Area
2 feet (0.7 m)
3 feet (1 m)

25% Lime
10% Clay
65% Sand

LEVEL B
allows for good water drainage from rain or irrigation.

Transgenic Crop

Biotechnology is used to create plants that can be cultivated in soils which, under normal conditions, would not be adequate (for instance, soils with high salinity).

Planting	Winter
Harvesting	Summer/Autumn

1 DNA
Genetic material is chosen.

2 GENES
The genes that have the desired characteristic are isolated.

3 BACTERIAL DNA
The genes are inserted into a bacterial plasmid.

4 MULTIPLICATION
Bacteria are cultivated to replicate the altered plasmids.

5 TRANSFER
The genes are inserted into the DNA of the plant.

6 NEW FRUITS
Plants are obtained that produce tomatoes with the desired characteristic.

DRY CLIMATES
These climates are not appropriate for planting tomatoes that are not modified, but they can be used to grow modified crops.

HIGH YIELD
The cultivated fields are designed to make maximum use of the available space.

LATE CROP
Transgenic tomatoes mature more slowly than tomatoes that have not been modified.

SALINE SOILS
Due to a shortage in rain, the minerals remain in Level A and increase its salinity.

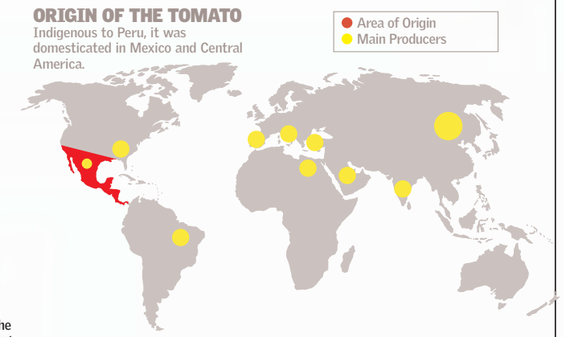
LEVEL A
High concentration of salts

40% Clay
30% Sand
30% Lime

LEVEL B
The clays retain water that soaks into the soil.

More
plants per acre are desired.

ORIGIN OF THE TOMATO
Indigenous to Peru, it was domesticated in Mexico and Central America.



Hydroponic Cultivation

Water and nutrients are sufficient to grow tomatoes. For this reason, it is possible to grow crops in inert substrates without any soil. This technique is very useful for obtaining tomatoes in desert areas and for making them available for harvest at any time of the year.

HYDROPONIC GREENHOUSES
allow growers to control the light, water, nutrients, and temperature of cultivation.

WATER TANK
contains water with an optimal amount of nutrients.

Drip-Control Flow Valve

The water flows under the force of gravity.

Irrigating Pipes

PUMP
Propels the water toward the irrigation tank

Troughs

COLLECTING TANK
The water is collected, and its physical and chemical properties are analyzed.

WATER
Water has long been known to be vital to plants.

SUBSTRATE
Inert materials, such as gravel or sand, work as substrates.

64-77° F
(18-25° C)
IS THE OPTIMAL TEMPERATURE.

MOST COMMON INFESTATIONS

Red Spider Mite
Tetranychus turkestani

Sweet Potato Whitefly
Bemisia tabaci

Green peach aphid
Myzus persicae

Olive Oil

Olive oil has been a part of people's diet since antiquity, and even today it is one of the most popular oils because of its flavor and nutritious properties. Obtaining high-quality olive oil involves a chain of processes that begins at the tree and ends with the packaging of the end product. The quality begins in the fields and depends on a combination of soil, climate, oil variety, and cultivation and harvesting techniques. The remaining operations in the extraction process (transportation, storage, manufacturing, and extraction of the oil) are responsible for maintaining that quality.

Olive
Olea europaea

22 pounds (10 kg)

IS THE QUANTITY OF OLIVES NEEDED TO EXTRACT **0.5 GALLON (2 L)** OF OIL.

TYPES OF OIL

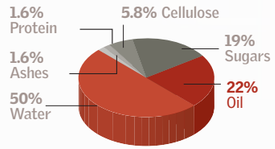
The classification of oil depends on the manufacturing process and on the properties of the product. The shorter the processing, the higher the quality.

Virgin Olive Oil is obtained by pressing, without any refining. It has less than 2 percent acidity.

Refined Olive Oil When this oil is refined, filtering soils are first added to purify it and then decanted. Its acid content is lower than that of virgin olive oil.

Olive Oil can also be obtained by treating the residues with solvents.

COMPOSITION OF AN OLIVE



THE QUALITY OF THE OIL

The oil that comes out of the first pressing from good quality fruits and with an acid level lower than 0.8 percent is called extra virgin. After this pressing the other levels of oil quality are obtained.

PRESS The press has a hydraulic mechanism that compresses the disks.

DISKS The olive paste is placed between them to be pressed.

1 Cultivation

Plowed land, a moderate climate, an altitude of up to 2,300 feet (700 m) above sea level, and up to 15 inches (40 cm) of rain per year sum up the conditions needed for the development of olive plants.

NEW PLANTINGS are propagated through staking, layering, or the taking of cuttings.

80 to 120 plants IS THE OPTIMUM DENSITY PER ACRE (0.4 HA).

COLLECTION Harvesting is done by hitting the tree branches, either by hand or mechanically, so that the fruits fall to the ground.

2 Washing and Classification

The fruits are carefully washed with water and then classified according to their variety.

3 Milling

Machines break open the fruit and mix it to create a homogenous paste. This must be done on the day the fruit is harvested.

STONE WHEEL Hammer systems are also used.

4 Pressing

Traditionally, the paste that includes the entire olive is placed on a system of stacked discs and then compressed by a hydraulic press.

FILTER Centrifugal machines are now used.

RESIDUE can be used to obtain other oils.

5 Refining

The oil obtained is separated from the other solid residues, impurities, and water. Since antiquity, this process has been carried out by decantation, which requires letting the oil sit undisturbed after it comes out of the press. Today it can also be carried out with vertical centrifugal machines.

STAINLESS STEEL HOPPER The residues are decanted at a temperature that is low, but not too low: oil crystallizes between 32° and 36° F (0°-2° C).

HOMOGENIZING The oil from several hoppers is mixed in the final stage to obtain a uniform product.

Large Residues

Residues

3 months IS THE LENGTH OF THE REFINING PERIOD.

6 Storage

Virgin olive oil has nonfat components that have to be preserved during storage and packaging. It must be kept in a dark place at a stable temperature.

THINGS TO AVOID

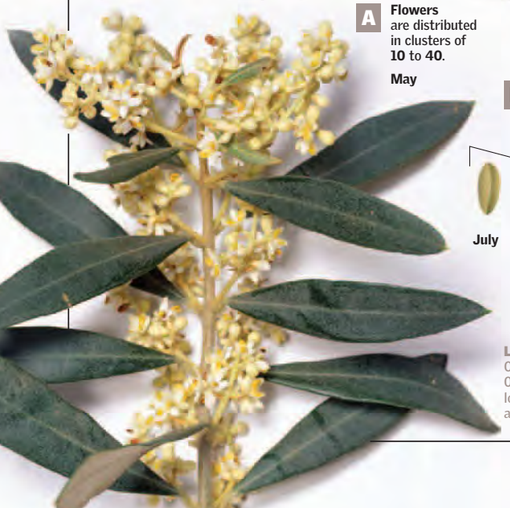
Contact with Air
Heat
Exposure to Light

BOTTLE This is how the oil is sent to the market.

7 Bottling

is carried out in a plant, although sometimes it is done manually to ensure product quality. Glass, aluminum, and plastic containers are used. It cannot be stored where it will be exposed to light, odors, or heat for extended periods.

OLIVE GROWTH STAGES (In the Southern Hemisphere)



A Flowers are distributed in clusters of **10** to **40**.

May

B Growth The pit or drupe (endocardium) has hardened; the fruit grows.

July

August

September

LEAVES Opposed and lengthened, 0.8 to 3 inches (2-8 cm) long, and with a pointed apical meristem

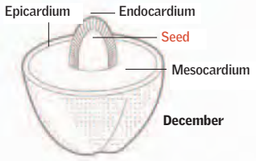
C Green Olive The appearance of this color tells us the fruit is edible.

October

D Maturing Purple spots begin to show.

November

E Mature Fruit The oxidation process has given it a black color.



December

Alternating Years

After a good crop, olive trees usually do not produce well the following year.

From Tree to Paper

The basic process of manufacturing paper has not changed for 2,000 years, although technology today allows us to manufacture paper in quantities that are immeasurably greater than those of the papyrus produced in antiquity. Paper is manufactured from a slurry that contains cellulose from tree trunks. Today the paper industry consumes 4 billion tons of wood each year. Worldwide, one of the most commonly used trees for paper manufacture is the eucalyptus because of its quick growth, its capacity to resprout trees from the stumps of young trees, its wood's quality, its consistency, and its yield. A disadvantage of eucalyptus is that it requires more water for its growth than most other trees do.

Eucalyptus
Eucalyptus globulus

1 Cultivation

The seedlings are obtained in greenhouses and are transplanted outdoors in furrows in the soil.

21,000 gallons (80,000 l)
OF WATER ARE NEEDED DAILY TO IRRIGATE 1 ACRE (0.4 HA).

TRACTOR
Opens the furrows in the earth

GREENHOUSE
Keeps seedlings between 69° and 80° F (21-27° C)

SEEDLINGS
are transplanted without using a hoe in order not to bend the plant.

WEEDING AND FUMIGATION
eliminate weeds and other plants.

GROWTH RATE
After approximately 10 years the growth rate slows.

Wood Production by Hectare (1 ha = 2.5 ac)
300
250
50
0
0 5 10 15 Years
Initial Maximum Moderate

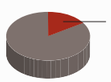
SOIL
Claylike and siliceous, with a pH between 5 and 7

STAKE
Helps keep the plant upright

TRANSPLANT
The plant is placed in the center of the hole by hand.

FERTILIZED
In furrows perpendicular to the incline of terrain to prevent soil erosion by the water

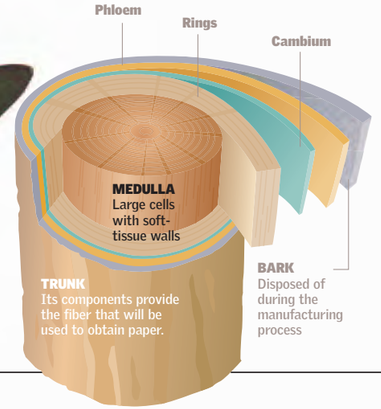
4 billion
TONS OF WOOD IS CONSUMED EVERY YEAR.



USES OF EUCALYPTUS GLOBULUS

FLOWER
In Australia the flower is most important for honey production.

LEAVES
Their resin is used in making perfumes.



2 Clear-Cutting

The timing of the clear-cutting will determine the financial success of the forestry venture. Replanting takes place right away.

10-13 years
IS THE OPTIMAL AGE FOR CUTTING.

CLEAR-CUTTING MACHINE
Cuts cleanly without damaging the bark

TRANSPORTATION
By trunks 8 feet (2.5 m) long

50 cubic feet (15 cu m)
IS THE AMOUNT OF WOOD PRODUCED PER HECTARE.

4 tons
IS THE AMOUNT OF WOOD NEEDED TO PRODUCE ONE TON OF CELLULOSE.

About **80,000 gallons (300,000 l)**
OF WATER PER TON OF WOOD IS REQUIRED FOR THE PRODUCTION OF CARDBOARD, AND ABOUT 50,000 GALLONS OF WATER PER TON (200,000 L PER MT) OF WOOD ARE USED IN THE PRODUCTION OF PRINTING PAPER.

3 Debarking, Washing, and Splintering

The bark is separated from the trunk and eliminated from the industrial process. The debarked trunk is washed and cut into chips to facilitate handling.

DEBARKER
Machine with toothed cylinders

WASHER
Eliminates sand and impurities

CHIPPING MACHINE
The wood is cut into chips.

4 Manufacture of the Pulp

The fibers are separated and suspended in water so they can be purified and bleached.

5 Bleaching and Inclusion of Additives

Bleaching is done with hydrogen peroxide, oxygen, sodium hypochlorite, and other chemicals; glues, kaolin, talcum, plaster, and colorants can be added.

6 Forming the Paper

The mixture of pulp, suspended in water, passes into a machine with screens that hold the fibers and allow the water to drain off. Sheets of paper are the result.

7 Drying

Heated rotating cylinders are used to press some of the remaining water from the paper. The final moisture content depends on the type of paper being made.

DRYING ROLLERS
leave the water content of the paper between 6 and 9 percent.

8 Rolling and Converting

The dried paper is rolled onto reels, and the rolls are cut. The paper can later be cut into various sizes for distribution and sale.

Healing Plants

Among nature's many gifts are herbs, plants, and flowers that, since antiquity, have been used from generation to generation for therapeutic purposes. Since humans began to care for their health, these plants have been a key source of nutrition and healing. Likewise, modern medicine uses compounds derived from or obtained from herbs, roots, stems, leaves, flowers, and seeds.

Contributions from the New World

Various plants were found to possess an impressive number of substances that could be used for therapeutic purposes, as antibiotics, contraceptives, anesthetics, and antipyretics (fever reducers), among others. One example is quinine, used in the treatment of malaria, which was originally obtained from the bark of the quinine tree (*Chinchona* species), a tree native to South America.

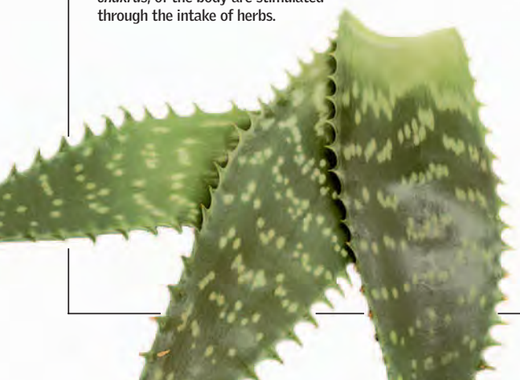
SHAMANS
fulfill a central role in ancient communities as repositories of wisdom. Shamans seek to cure illnesses naturally, by means of herbs, roots, and other vegetable substances.

ECHINACEA SP.
The medicinal plant most used by native North Americans. This plant stimulates the immune system.

INDUSTRY
Echinacea is consumed around the world as a natural medicine.

Ayurvedic Medicine in India

The knowledge of life is the central principle of ayurvedic medicine. The representation of the elements that form the Universe (fire, air, water, earth, and ether) in three humors (*vata*, *pitta*, and *kapha*) indicate a person's health and temperament. The energy centers, or *chakras*, of the body are stimulated through the intake of herbs.



THE THREE TYPES OF HUMORS

Vata (wind) is associated with air and ether, *pitta* (anger) is associated with fire and water, and *kapha* (phlegm) is associated with earth and water. A holistic approach, Ayurvedic medicine provides integrated treatments that link physical care and meditation with nutrition.

VATA
(Wind)
In excess, it influences the intestines, the colon, the ears, the bones, the hips, and the skin.

DESCRIPTION
It is associated with a melancholic personality, characteristic of dreamy and erratic people.

PITTA
(Anger)
It affects the liver, gallbladder, stomach, eyes, skin, and pancreas.

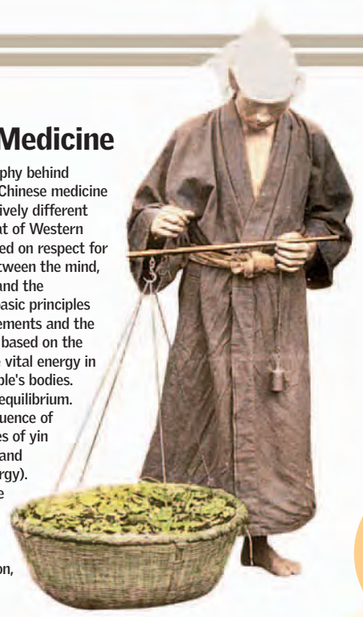
DESCRIPTION
It represents a choleric personality—people who are decisive, with a tendency to embrace new ideas.

KAPHA
(Phlegm)
In excess, it can affect the throat, airways (upper and lower), and joints.

DESCRIPTION
It is associated with tranquility and serenity, typical characteristics of persons with a naturally sensitive attitude.

Chinese Medicine

The philosophy behind traditional Chinese medicine involves a qualitatively different approach from that of Western medicine. It is based on respect for the interaction between the mind, the body, energy, and the environment. Its basic principles include the five elements and the yin and yang. It is based on the concept of chi, the vital energy in equilibrium in people's bodies. Chi regulates lost equilibrium. It is under the influence of the opposing forces of yin (negative energy) and yang (positive energy). Traditional Chinese medicine includes herbal therapies, nutrition, physical exercise, meditation, acupuncture, and healing massages.



TAI CHI OR TAI JI
is the generating principle of all things, according to Chinese philosophy. It is represented with the yin and the yang, which together make up the Taoist symbol known as the "Taijitu diagram." In order to maintain good health, it is necessary to balance yin and yang.

THE THEORY OF THE FIVE ELEMENTS
Chinese tradition adds metal to the elements of the Greek model (water, fire, air, and earth). The interaction among all these elements must be kept in equilibrium, with no single element predominating over the others. Should an imbalance occur, an illness might appear.

Bitter Herbs
Their action is focused on the heart and the small intestine. They lower fevers and sensations of heat, and they redirect vital energy, or chi.

YIN
Motherwort (*Leonurus cardiaca*), Elecampane (*Inula helenium*), English lavender (*Lavandula angustifolia*)

YANG
Hawthorn (*Crataegus oxyacantha*), sour orange (*Citrus aurantium*), meadowsweet (*Filipendula ulmaria*)

Sweet Herbs
are tonic and nutritious. They harmonize with other herbs, relieve pain, and stop the progression of severe illnesses.

YIN
Garden angelica (*Angelica archangelica*), Italian cyprus (*Cupressus sempervirens*), common hop (*Humulus lupulus*), rosemary (*Rosmarinus officinalis*)

YANG
Greater plantain (*Plantago major*), dandelion (*Taraxacum officinale*), marjoram (*Origanum majorana*)

YIN
Chamomile (*Matricaria chamomilla*), cinnamon (*Cinnamomum zeylanicum*), yellow gentian (*Gentiana lutea*), Minor centaury (*Centaurium umbellatum*)

YANG
Lemon (*Citrus limonum*), common juniper (*Juniperus communis*), lemon balm (*Melissa officinalis*), cranberry (*Vaccinium myrtillus*), olive (*Olea europaea*)

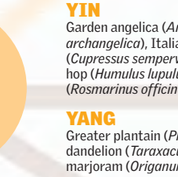
Salty Herbs
are refreshing; they soften hard spots, lubricate the intestines, and promote their emptying. They reduce constipation, kidney stones, gout, etc.

Sour Herbs
basically act on the liver and the gallbladder. They activate bilious secretions.

YIN
Heather (*Calluna vulgaris*), blessed milk thistle (*Silybum marianum*), ginseng (*Panax ginseng*)

Spicy Herbs
induce sweating, blood circulation, and chi, or vital energy. They are generally used for superficial disorders.

YIN
Ginger (*Zingiber officinale*), peppermint (*Mentha piperita*), thyme (*Thymus vulgaris*)



YANG
Shepherd's purse (*Capsella bursa-pastoris*), red sandwort (*Arenaria rubra*), rough bindweed (*Smilax aspera*)

Ginger

YANG
Corn poppy (*Papaver rhoeas*), Tasmanian bluegum (*Eucalyptus globulus*), common borage (*Borago officinalis*)

Fungi

AMANITA MUSCARIA
The quintessential toadstool has unpleasant psychoactive effects. Depending on the dose, they range from dizziness, muscle cramps, and vomiting to amnesia.

ANOTHER WORLD 82-83
THE DIET OF FUNGI 84-85
POISON IN THE KINGDOM 86-87
PATHOGENS 88-89
DESTROYING TO BUILD 90-91

For nearly a billion years the ability of fungi to break down substances has been important to life on Earth. These life-forms break down carbon compounds and return carbon and other elements to the environment to be used by other organisms. They interact with roots, enabling them to better absorb water and mineral nutrients. For many years fungi were classified within the plant kingdom. However, unlike plants, they cannot produce their own food. Many are parasites. Some fungi are pathogens—they can cause sickness in humans, animals, or plants. ●

Another World

For many years fungi were classified within the plant kingdom. However, unlike plants, they are heterotrophic—unable to produce their own food. Some fungi live independently, whereas others are parasitic. Like animals, they use glycogen for storing reserves of energy, and their cell walls are made of chitin, the substance from which insects' outer shells are made.

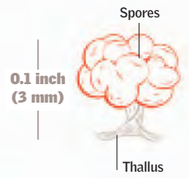
Chanterelle Mushroom
Cantharellus cibarius

Fungi: A Peculiar Kingdom

Fungi can develop in all sorts of environments, especially damp and poorly lit places, up to elevations of 13,000 feet (4,000 m). They are divided into four large phyla, in addition to a group of fungi called "imperfect" because they generally do not reproduce sexually. At present, 15,000 species of fungi fall into this category. DNA analysis has recently reclassified them as Deuteromycetes.

Chytridiomycota

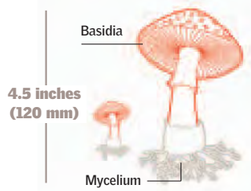
are the only fungi that, at some point in their lives, have mobile cells—male and female gametes, which they release into water in order to reproduce. They live in water or on land, feeding on dead material or living as parasites on other living organisms. Their cell walls are made of chitin.



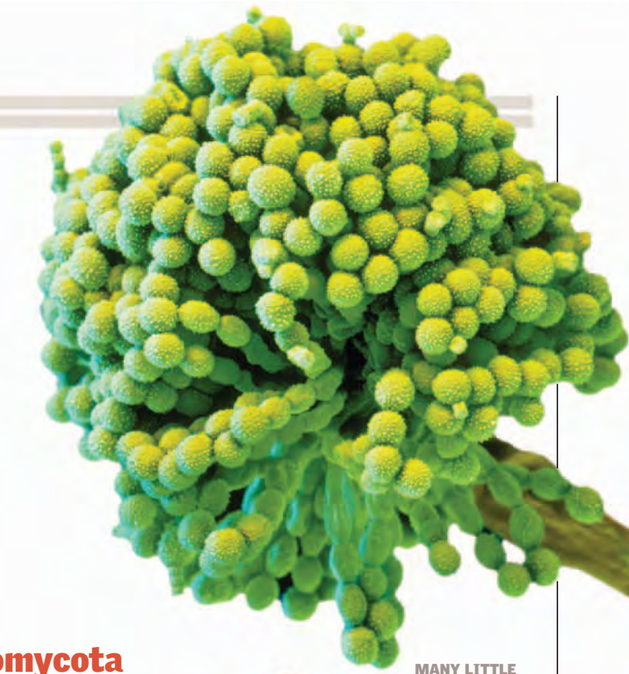
VARIETY
There are great anatomical differences among the Chytridiomycetes. In the same reproductive phase they can produce haploid and diploid spores.

Basidiomycota

This phylum, which includes mushrooms, is the most familiar of the fungi. The mushroom's reproductive organ is its cap. Its branches grow underground or into some other organic substrate.



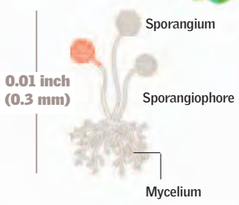
CAPPED MUSHROOMS
With its recognizable shape, the mushroom's cap protects the basidia, which produce spores.



Black Bread Mold
Rhizopus nigricans

Zygomycota

is a phylum of land-growing fungi that reproduce sexually with zygosporangia, diploid cells that do not break their cell walls until conditions are right for germinating. They also reproduce asexually. Most zygomycetes live in the soil and feed on plants or dead animal matter. Some live as parasites on plants, insects, or small land animals.



MANY LITTLE POUCHES
Its spores are formed when two gametes of opposite sexes fuse. It can also reproduce asexually, when the sporangium breaks and releases spores.

39° to 140° F

(4°-60° C)
THE TEMPERATURE RANGE IN WHICH MOST FUNGI CAN LIVE IN HUMID CLIMATES

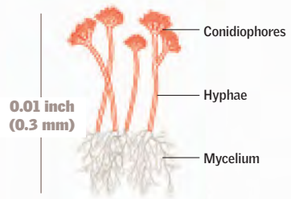
80,857

DIFFERENT SPECIES
HAVE BEEN IDENTIFIED IN THE FUNGI KINGDOM. THERE ARE BELIEVED TO BE APPROXIMATELY 1,500,000 SPECIES.

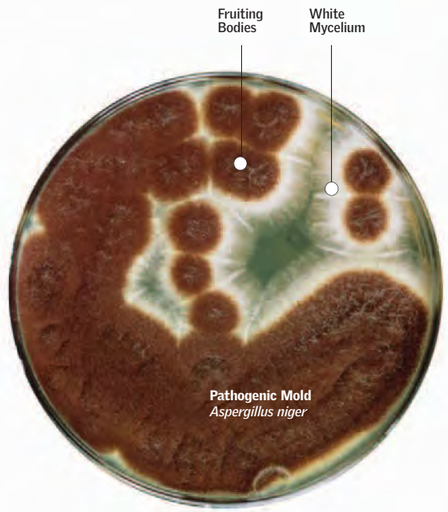
Slime Mold
Physarum polycephalum

Deuteromycota

are also called "imperfect fungi" because they are not known to have a form of sexual reproduction. Many live as parasites on plants, animals, or humans, causing ringworm or mycosis on the skin. Others—such as *Penicillium*, which produces penicillin, and *Cyclospora*—have great medicinal and commercial value.



OF UNKNOWN SEX
In Deuteromycetes, conidia are tiny spores that function asexually. They are contained in structures called conidiophores.

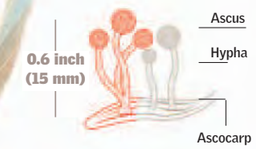


Pathogenic Mold
Aspergillus niger

Ascomycota

is the phylum with the most species in the Fungi kingdom. It includes yeasts and powdery mildews, many common black and yellow-green molds, morels, and truffles. Its hyphae are partitioned into sections. Their asexual spores (conidia) are very small and are formed at the ends of special hyphae.

EXPLOSIVE
At maturity the asci burst. The explosion releases their sexual spores (ascospores) into the air.



Ergot
Claviceps purpurea

The Diet of Fungi

Fungi do not ingest their food like animals. On the contrary, they absorb it after breaking it down into small molecules. Most of them feed on dead organic material. Other fungi are parasites, which feed on living hosts, or predators, which live off the prey they trap. Many others establish relationships of mutual benefit with algae, bacteria, or plants and receive organic compounds from them.

Chemical Transformation

The organic or inorganic substances that fungi feed on are absorbed directly from the environment. Fungi first secrete digestive enzymes onto the food source. This causes a chemical transformation that results in simpler, more easily assimilated compounds. Basidiomycetes are classified according to their diet. For example, they colonize different parts of a tree depending on the nutrients they require.

PARASITES

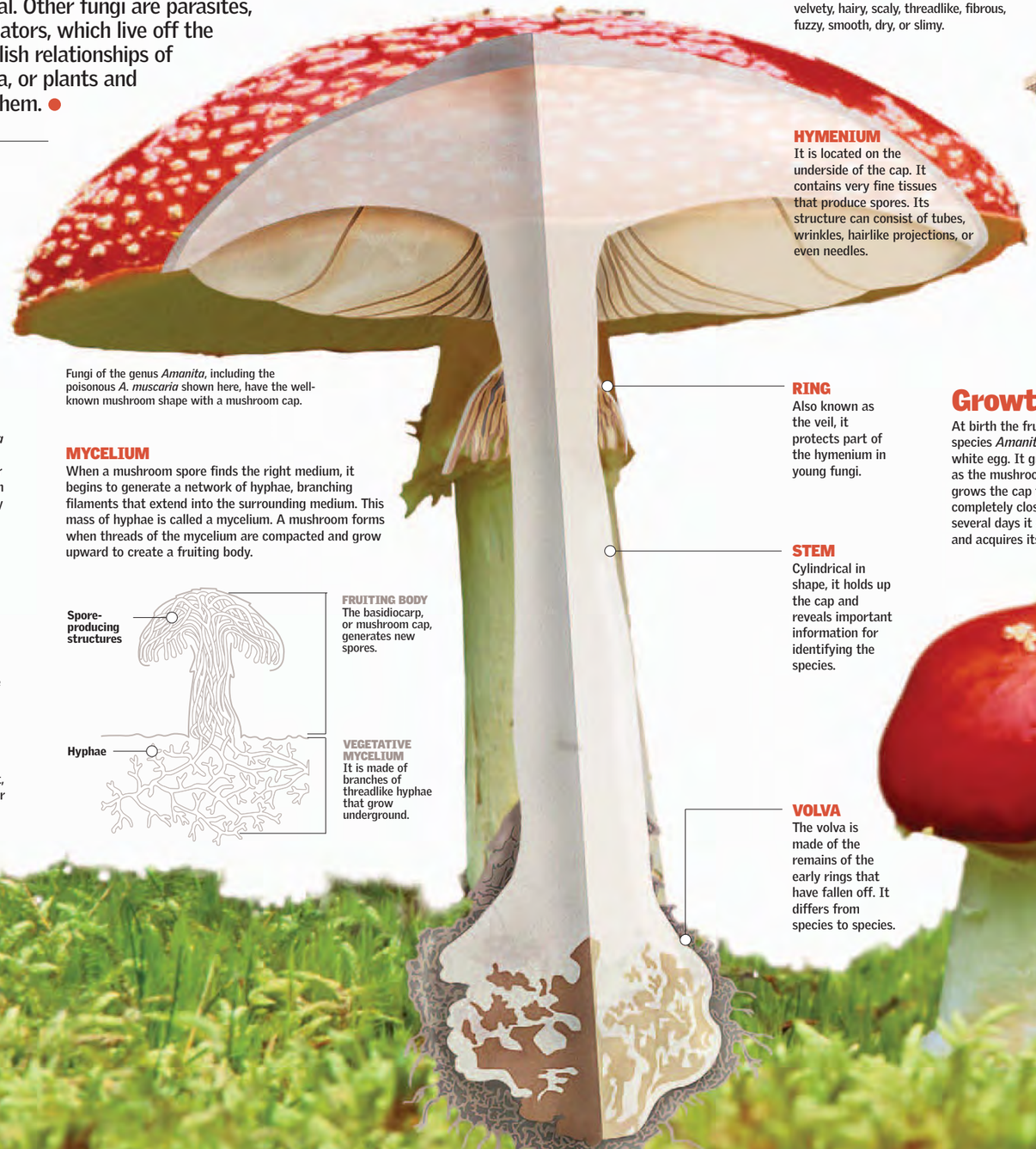
Fungi such as *Ceratocystis ulmi* and *Agrocybe aegerita* (shaded areas on the leaf) live at the expense of other plants, which they can even kill. Others live parasitically off animals.

SAPROBES

There is no organic material that cannot be broken down by this type of fungus. They actually live on the dead parts of other plants, so they cause no harm to the host.

SYMBIOTIC

While feeding off the plant, they help it to obtain water and mineral salts more easily from the soil. Each species has its own characteristics.



Fungi of the genus *Amanita*, including the poisonous *A. muscaria* shown here, have the well-known mushroom shape with a mushroom cap.

CAP

Besides being easy to spot, the cap is the fertile part of basidiomycetes; it contains spores.

CUTICLE

The skin, or membrane, that covers the cap, or pileus, is called the cuticle. It can have a variety of colors and textures, such as velvety, hairy, scaly, threadlike, fibrous, fuzzy, smooth, dry, or slimy.

GILLS

are the structures that produce spores. Their shape varies according to the species.

HYMENIUM

It is located on the underside of the cap. It contains very fine tissues that produce spores. Its structure can consist of tubes, wrinkles, hairlike projections, or even needles.

RING

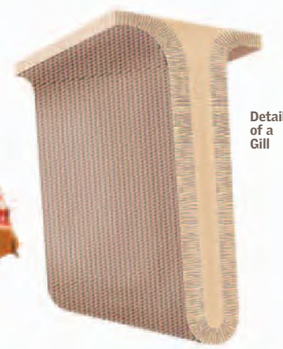
Also known as the veil, it protects part of the hymenium in young fungi.

STEM

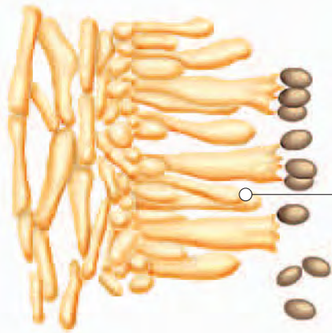
Cylindrical in shape, it holds up the cap and reveals important information for identifying the species.

VOLVA

The volva is made of the remains of the early rings that have fallen off. It differs from species to species.



Detail of a Gill



BASIDIA

are fine structures that contain groups of four cells, which are able to reproduce.

MYCELIUM

When a mushroom spore finds the right medium, it begins to generate a network of hyphae, branching filaments that extend into the surrounding medium. This mass of hyphae is called a mycelium. A mushroom forms when threads of the mycelium are compacted and grow upward to create a fruiting body.

FRUITING BODY

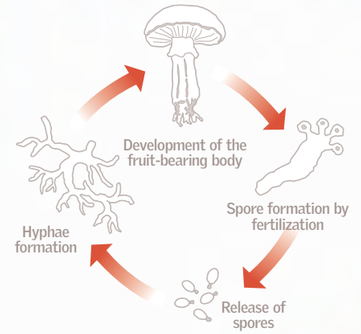
The basidiocarp, or mushroom cap, generates new spores.

VEGETATIVE MYCELIUM

It is made of branches of threadlike hyphae that grow underground.

Growth

At birth the fruiting body of the species *Amanita muscaria* looks like a white egg. It grows and opens slowly as the mushroom's body unfolds. As it grows the cap first appears completely closed. During the next several days it opens like an umbrella and acquires its color.



LIFE CYCLE OF A FUNGUS

Fungi produce spores during sexual or asexual reproduction. Spores serve to transport the fungus to new places, and some help the fungus to survive adverse conditions.

Did You Know?

Fungi can break down an impressive variety of substances. For example, a number of species can digest petroleum, and others can digest plastic. Fungi also provided the first known antibiotic, penicillin. They are now a basic source of many useful medical compounds. Scientists are studying the possibility of using petroleum-digesting fungi to clean up oil spills and other chemical disasters.

Strobilurus esculentus

lives on the cones of various pine trees.

HALLUCINOGENIC MUSHROOM
Psilocybin aztecorum

Poison in the Kingdom

A poisonous fungus is one that, when ingested, causes toxic effects. In terms of its effects on the eater, the toxicity can vary according to the species and to the amount ingested. At times poisoning is not caused by eating fungi but by eating foods, such as cereal products, that have been contaminated by a fungus. Rye, and to a lesser extent oats, barley, and wheat, can host toxic fungi that produce dangerous mycotoxins. These mycotoxins can cause hallucinations, convulsions, and very severe damage in the tissues of human organs. ●

ERGOTISM (ST. ANTHONY'S FIRE)

Attack on Rye

Ergot (*Claviceps purpurea*) is a parasite of rye and produces alkaloid mycotoxins—ergocristine, ergometrine, ergotamine, and ergocryptine. When barley with ergot is processed for use in food, the mycotoxins can be absorbed when eaten. All these toxic substances can act directly on nerve receptors and cause the constriction of blood vessels.

1. Release

Within the enclosing structures a stroma, or compact somatic body, is formed. Inside it reproductive growths develop, which contain a large number of perithecia.

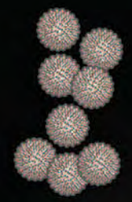
ERGOT
Claviceps purpurea

2. Fruit

The perithecium is a type of fruiting, or reproductive, body in ascomycetes. It is a type of closed ascocarp with a pore at the top. The asci are inside the perithecium.

3. Spores

The asci are sac-shaped cells that contain spores called ascospores. In general, they grow in groups of eight and are light enough to be scattered into the air.



4. Parasites

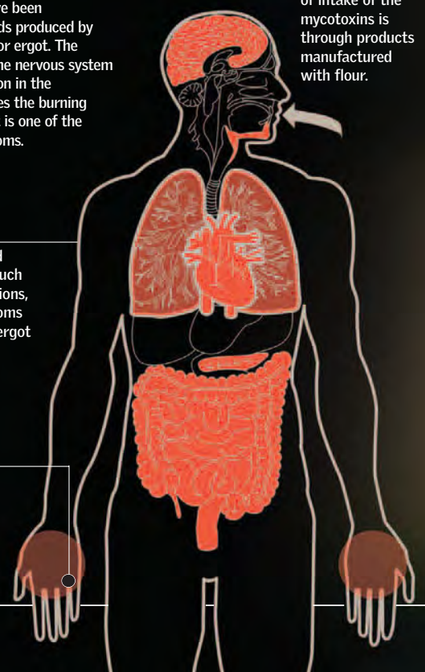
Ascospores of sexual origin or asexual conidia develop as parasites in the ovary of the rye flower. They cause the death of its tissues and form sclerotia. In some languages ergot's name is related to the word for "horn" because of sclerotia's hornlike shape.

Ergotism

Ergotism, or St. Anthony's Fire, is a condition caused by eating products such as rye bread that have been contaminated with alkaloids produced by *Claviceps purpurea* fungi, or ergot. The alkaloids typically affect the nervous system and reduce blood circulation in the extremities, which produces the burning sensation in the limbs that is one of the condition's notable symptoms.

NERVOUS SYSTEM
Lethargy, drowsiness, and more severe conditions, such as convulsions, hallucinations, and blindness, are symptoms caused by the effects of ergot on the nervous system.

EXTREMITIES
Ergotamine alkaloids cause the constriction of blood vessels, leading to gangrene.



INGESTION
The main means of intake of the mycotoxins is through products manufactured with flour.

Derived from Rye

In Europe during the Middle Ages wheat bread was a costly food, not part of the common diet. Most people ate bread and drank beer prepared from rye. This made them susceptible to ingesting mycotoxins from *Claviceps purpurea*. Thus, the largest number of cases of ergotism occurred during this time. Today preventative controls in the production of bread and related products from rye and other cereals have greatly reduced instances of ergotism.

Poisonous Mushrooms

Eating the fruiting bodies of some species can be very dangerous if it is not clearly known which are edible and which are poisonous. There is no sure method for determining the difference. However, it is known for certain that some species—such as certain species of the genera *Amanita, Macrolepiota*, and *Boletus*—are poisonous.

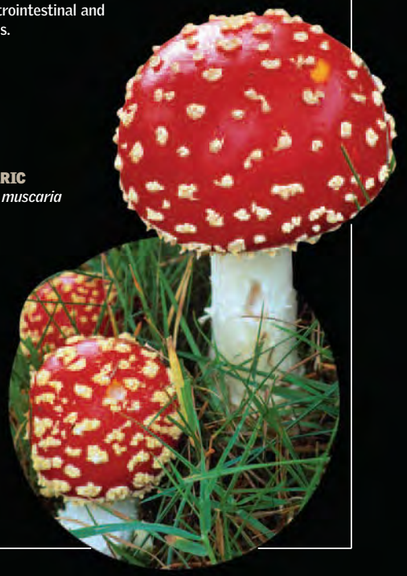
DESTROYING ANGEL
Amanita virosa

Pretty But Deadly

This mushroom is toxic to the liver. It grows from spring to fall, often in sandy, acidic soil in woodlands and mountainous regions. Its cap is white and 2 to 5 inches (5-12 cm) in diameter. Its stem and gills are also white, and the gills may appear detached from the stem. The base of the stem has a cuplike volva, but it may be buried or otherwise not visible.

Insecticide

The fly agaric's name is thought to come from its natural fly-killing properties. Its cap is typically red and 6 to 8 inches (15-20 cm) in diameter. It may be covered with white or yellow warts, but they are absent in some varieties. The stem is thicker at the base, which looks cottony. It also has a large white ring that looks like a skirt. It grows in summer and fall in coniferous and deciduous forests.
If eaten, it causes gastrointestinal and psychotropic symptoms.

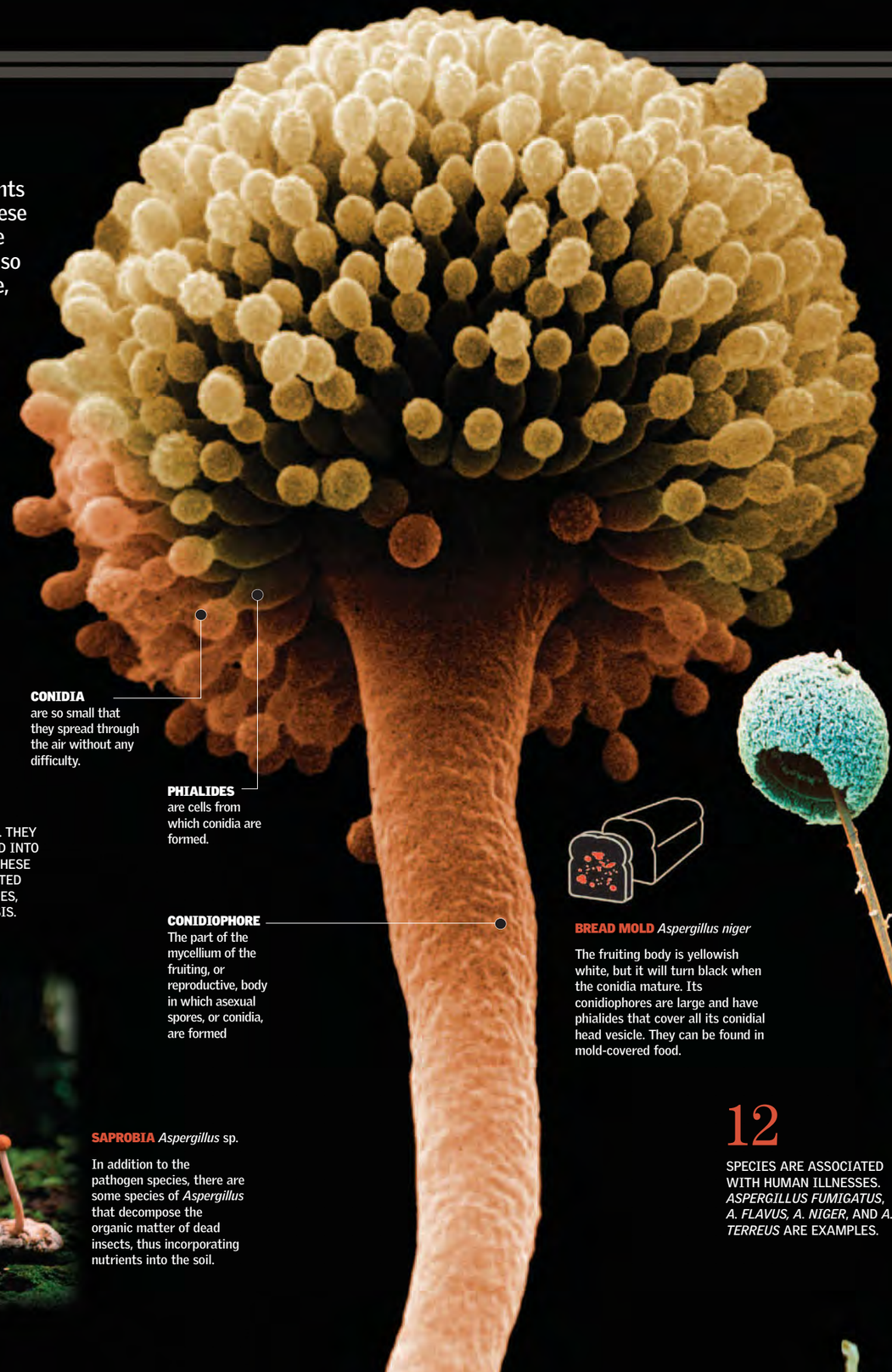


FLY AGARIC
Amanita muscaria

Pathogens

Fungi that are able to cause illnesses in people, animals, or plants are called pathogens. The nocive, or toxic, substances that these organisms produce have negative effects on people and cause significant damage to agriculture. One reason these pathogens are so dangerous is their high tolerance to great variations in temperature, humidity, and pH. *Aspergillus* is a genus of fungi whose members create substances that can be highly toxic.

CONIDIA CHAIN
Conidia are asexual spores that form at the ends of the hyphae. In this case they group together in chains.



CONIDIA
are so small that they spread through the air without any difficulty.

PHIALIDES
are cells from which conidia are formed.

CONIDIOPHORE
The part of the mycellium of the fruiting, or reproductive, body in which asexual spores, or conidia, are formed

Aspergillum

Aspergillus are "imperfect" fungi, or deuteromycetes, that are characterized by having reproductive structures called conidial heads. The head is composed of a vesicle that is surrounded by a crown of phialides shaped like a bottle, at the end of which spore chains form.

CONIDIAL HEAD
Has a greenish mycellium and short and abundant conidiophores.

ALLERGENICS *Aspergillus flavus*

This species is associated with allergic reactions in people with a genetic predisposition to this allergy. They also cause the contamination of seeds, such as peanuts. They produce secondary metabolites, called micotoxins, that are very toxic.

900

THE NUMBER OF *ASPERGILLUS* SPECIES. THEY HAVE BEEN CLASSIFIED INTO 18 GROUPS. MOST OF THESE SPECIES ARE ASSOCIATED WITH HUMAN ILLNESSES, SUCH AS ASPERGILLOSIS.

SAPROBIA *Aspergillus* sp.

In addition to the pathogen species, there are some species of *Aspergillus* that decompose the organic matter of dead insects, thus incorporating nutrients into the soil.

BREAD MOLD *Aspergillus niger*

The fruiting body is yellowish white, but it will turn black when the conidia mature. Its conidiophores are large and have phialides that cover all its conidial head vesicle. They can be found in mold-covered food.

12

SPECIES ARE ASSOCIATED WITH HUMAN ILLNESSES. *ASPERGILLUS FUMIGATUS*, *A. FLAVUS*, *A. NIGER*, AND *A. TERREUS* ARE EXAMPLES.

OPPORTUNISTIC *Aspergillus fumigatus*

This pathogen can affect people whose immune systems are weakened. It can cause serious invasive diseases.

Destroying to Build

Yeasts, like other fungi, decompose organic material. This capacity can be beneficial, and, in fact, human beings have developed yeast products for home and industrial use, such as bread, baked goods, and alcoholic beverages, that attest to its usefulness. Beer manufacturing can be understood by analyzing how yeasts feed and reproduce and learning what they require in order to be productive.

Precious Gems

Yeast from the genus *Sacchromyces cerevisiae* can reproduce both asexually and sexually. If the concentration of oxygen is adequate, the yeasts will reproduce sexually, but if oxygen levels are drastically reduced, then gemation will take place instead. Gemation is a type of asexual proliferation that produces child cells that split off from the mother cell. Starting with barley grain, this process produces water, ethyl alcohol, and a large quantity of CO_2, the gas that forms the bubbles typically found in beer.

Fermentation

Under anaerobic conditions yeasts can obtain energy and produce alcohol. By means of the alcoholic fermentation process they obtain energy from pyruvic acid, a product of the breakdown of glucose by glucolysis. In this process CO_2 is also produced and accumulated, as is ethyl alcohol. The carbon dioxide will be present in the final product: the beer.

Cycle

GROW AND MULTIPLY
As long as they have adequate nutrients, yeasts will continuously repeat their reproductive life cycle.

1 MEIOSIS
A diploid cell forms four haploid cells.

2 SPORES
A sac called an ascus is formed that contains ascospores of yeast.

3 RELEASE OF THE ASCOSPORES
The opening of the ascus releases the spores, which then reproduce by mitosis.

4 UNION OF THE ASCOSPORES
The haploid cells fuse and form a new diploid cell.

5 GEMATION
Under the right conditions the diploid cells begin to reproduce asexually.

6 MULTIPLICATION
A large number of cells are produced in this stage.

WINE YEAST
Yeast is also used to produce wine. In wine production, however, the CO_2 that is produced is eliminated.

Yeast
Saccharomyces ellipsoideus

Homemade Bread

Many products are made with yeasts, and one of the most important is bread. In the case of bread, yeasts feed off the carbohydrates present in flour. Bread products, unlike alcoholic beverages, need to have oxygen available for the yeast to grow. The fungi release carbon dioxide as they quickly consume the nutrients. The bubbles of carbon dioxide make the dough expand, causing the bread to rise.

Yeast
Saccharomyces cerevisiae

GEMATION
Buds, or gems, which will become independent in a new cell, are formed in different parts of a yeast.

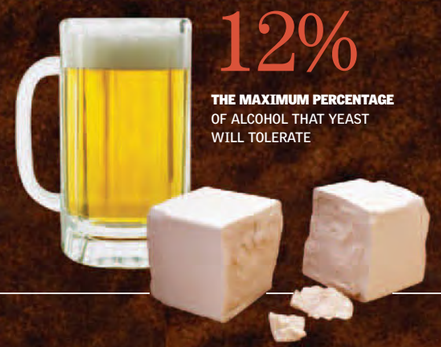
NUCLEUS
It coordinates all the cell's activities. Its duplication is vital in making each child cell the same as its progenitor cell.

MITOCHONDRIA
These subcellular structures become very active when the cell is in an environment rich in oxygen.

CELL MEMBRANE
The cell membrane controls what enters or exits the cell. It acts as a selective filter.

ENZYME PRODUCTION
Internal membrane systems produce the enzymes that regulate the production of alcohol and carbon dioxide in the cells.

VACUOLE
This organelle contains water and minerals that are used in the cell's metabolism. The concentration of these nutrients helps regulate the activity of the cell.



12%

THE MAXIMUM PERCENTAGE OF ALCOHOL THAT YEAST WILL TOLERATE

Glossary

Adventitious Root

Root that appears in unusual places, such as on the stem

Algae

Organisms of the Protist kingdom, at one time considered plants, but without roots, stems, or leaves. They live in water or in humid areas. They can be pluricellular or unicellular.

Allele

Gene variant that encodes a trait. One diploid cell contains one allele from each parent for each characteristic.

Anaerobic

Reaction, or series of reactions, that does not require oxygen

Analogy

Similarity produced in similar environments through the adaptation of species that do not have a common ancestor

Angiosperms

From the Greek *angion* (recipient) and *sperm* (seed). Plants with flowers whose seeds are contained in structures that develop into fruits.

Anther

Structure of the stamen composed of two locules and four pollen sacs

Asexual Reproduction

Process through which a single progenitor generates descendants identical to itself

ATP

Adenosine triphosphate. Molecule produced by the mitochondria, which functions as the main source of energy for cells.

Berry

Simple fleshy fruit formed by one or more carpels

Biome

Ecosystem that occupies a large area and is characterized by specific types of vegetation

Bryophytes

Group of small flowerless plants that comprise the hepaticae, anthocerotae, and mosses

Bulb

Modified structure of the stem in which starch accumulates in thickened leaves

Cambium

Interior part of the root and the stem of a plant that forms xylem on one side and phloem on the other. It makes stems grow thicker.

Carpel

Female part that bears the ovules of a flower. The grouping of carpels forms the gynoecium.

Cell

Smallest vital unit of an organism. Plant cells have a wall that is more or less rigid.

Cellular Membrane

Flexible cover of all living cells. It contains cytoplasm and regulates the exchange of water and gases with the exterior.

Cellular Respiration

Aerobic processes that extract energy from food, including glycolysis, oxidative phosphorylation, and the Krebs cycle. Eukaryote cells carry out these processes in the cytoplasm and the mitochondria.

Cellulose

Fibrous carbohydrate that a plant produces as part of its structural material. Main component of the cell wall.

Chitin

Polysaccharide that contains nitrogen. It is present in the cell walls of mushrooms.

Chlorophyll

Pigment contained in the chloroplasts of plant cells. It captures the energy of light during photosynthesis.

Chloroplast

Microscopic sac, located on the inside of green-plant cells, where the chemical processes of photosynthesis take place

Cilium

Short external appendage that propels a cell and is composed of microtubules

Class

Taxonomic group superior to order and inferior to phylum. For example, the Charophyceae class includes green algae related to higher plants.

Cotyledon

First leaf of flowering plants, found on the inside of the seed. Some store food and remain buried while the plant germinates.

Cytoplasm

Compartment of the cells of eukaryotes, marked by the cellular membrane and the membranes of the organelles of the cell

Deciduous

Describes a plant that loses all its leaves in specific seasons of the year

Dicotyledon

Flowering plant whose seed has two cotyledons

Diploid

Cell with two complete sets of chromosomes

DNA

Deoxyribonucleic acid. Double helix molecule with codified genetic information.

Drupe

Simple fleshy fruit that develops from hypogynous flowers—flowers in which the ovary lies above the point where the other flower parts are attached. It has one seed in its interior. Examples include the olive, peach, and almond.

Ecosystem

Grouping of the organisms of a community and the nonbiological components associated with their environment

Embryo

Product of an egg cell fertilized by a sperm cell; it can develop until it constitutes an adult organism.

Endodermis

Layer of specialized cells, composed of thicker cells; in young roots it is found between the bark and the vascular tissues.

Endoplasmic Reticulum

Network of membranes connected through the cytoplasm that serves as a site of synthesis and assembly for the cell to form its proteins

Enzyme

Protein that helps to regulate the chemical processes in a cell

Epidermis

The most external cellular layers of stems and leaves

Epiphyte

Plant that grows and supports itself on the surface of another plant but does not take water or nutrients from it

Family

Taxonomic category, inferior to order, that groups the genera

Fertilization

Fusion of the special reproductive cells (contained in the pollen and in the ovules) in order to give rise to a new plant

Filament

Structure, in the form of a thread, that forms the support of a flower's stamen

Fruit

Ovary or group of ovaries of a flower, transformed and mature. It contains the seeds.

Gametangium

Unicellular or multicellular structure from which the gametes, or reproductive sexual cells, originate

Gene

Unit of information of a chromosome. Sequence of nucleotides in the DNA molecule that carries out a specific function.

Genetic Drift

Phenomenon produced in small populations that demonstrates that the frequency of alleles can vary by chance or throughout generations

Germination

Process in which a plant begins to grow from a seed or a spore

Gymnosperm

Plants with seeds that are not sealed in an ovary. Examples are conifers (pine, fir, larch, cypress).

Gynoecium

Grouping of carpels of a flower that make up the female sexual organ of angiosperms

Haploid

From the Greek *haplous*, singular: cell with one set of chromosomes, unlike diploids. It is characteristic of the gametes, the gametophytes, and some mushrooms.

Haustoria

Vessels with which some parasitic plants penetrate other species in order to feed themselves from substances photosynthesized by the host

Host

Plant from which another organism (parasite) obtains food or shelter

Hyphae

Interwoven filaments that form the mycelium of fungi

Inflorescence

Groupings of flowers in a specific form on a peduncle

Kingdom

Taxonomic group superior to a phylum and inferior to a domain, such as the kingdom Plantae

Legume

Simple fruit of some species that come from one carpel divided in two. Examples are garbanzos and peas.

Lichen

The symbiotic union of a fungus and an alga; the food is synthesized by the algae and used by the fungus, which offers the alga a moist and protected habitat in which to live.

Lignin

A substance related to cellulose that helps form the woody parts of plants

Ligula

Petal developed on the border of the head of certain composite flowers. Its color may be blue or yellow, or more commonly, white, as in the case of daisies.

Macronutrient

Essential chemical element that a plant needs in relatively large quantities and that is involved in its vital processes. Examples are nitrogen and phosphorus.

Medulla

Basic tissue formed inside the vascular tissue

Meiosis

Type of cellular division in which two successive divisions of the diploid nucleus of a cell give rise to four haploid nuclei. As a result, gametes or spores are produced.

Meristem

Region of tissue consisting of cells that produce other cells through cellular division

Mitochondria

Organelle delimited by a double membrane. In it, the final stage of aerobic respiration is carried out, in which ATP is obtained from the decomposition of sugars.

Mitosis

Nuclear division that forms two descendant nuclei identical to the progenitor

Molecular Clock

Marker used to calculate the evolutionary distance between two species. It is evaluated by comparing the gradual accumulation of differences in amino acids among the proteins of each species.

Monocotyledons

Flowering plants with only one cotyledon. Examples are the onion, orchid, and palm.

Mycelium

Interwoven mass of hyphae of a fungus

Nectar

Sweet liquid, produced by flowers and some leaves, that attracts insects and birds, which serve as pollinating agents

Node

Axillary bud, the part of the stem of a plant where one or more leaves appear

Nucellus

Structure located inside plants with seeds, where the embryonic sac is developed

Nucleic Acid

A molecule that carries genetic information about the cell

Nucleus

The part of the cell that contains the DNA, which carries the genetic material

Osmosis

The movement of a liquid through a selectively permeable membrane

Ovary

The part of a flower consisting of one or more carpels and containing the ovules. Fertilized, it will form all or part of the fruit.

Ovule

The part of the ovary in flowering plants that contains the female sexual cells. After fertilization it transforms into seed.

Parasite

An organism that lives at the expense of another, from which it obtains its nutrients

Petal

Modified leaves that form the corolla

Phloem

Vessels that conduct the sap throughout the entire plant

Photorespiration

Process through which some plants close their stomas in order to avoid dehydration

Photosynthesis

Process through which the energy of light is used to produce carbohydrates from carbon dioxide and water

Phytoplankton

Group of free-living microscopic aquatic organisms with the capacity to carry out photosynthesis

Pollen

Fine powder of plants with seeds whose grains contain the male sexual cells

Pollination

Passage of pollen from the male organ of a flower to the female organ of the same flower or another

Polymer

Macromolecule formed from repeated structural units called monomers

Polypeptide

Polymer of amino acids; examples are proteins.

Protein

Macromolecule composed of one or more chains of amino acids. They define the physical characteristics of an organism and regulate its chemical reactions when they act as enzymes.

Protoplast

Plant cell without a cell wall

Rhizoids

Cellular formation or filament in the form of a thin and branching tube that attaches mosses to the soil

Rhizome

Horizontal subterranean stem

Ribosome

Organelle located in the cytoplasm that directs the formation of proteins on the basis of information given by the nucleic acids

Root

Organ that fixes a plant to the soil and absorbs water and minerals from it

Sap

Watery liquid that contains the products of photosynthesis and is transported by the phloem

Seed

Structure consisting of the embryo of a plant, a reserve of food called the endosperm, and a protective cover called the testa

Seedling

First sprouting of the embryo of a seed, formed by a short stem and a pair of young leaves

Sepal

Modified leaf that forms the outer covering of a flower that protects the bud before it opens

Sexual Reproduction

Reproduction based on the fertilization of a female cell by a male cell; it produces descendants different from both progenitors.

Sori

Set of sporangia found on the underside of fern leaves

Spore

Reproductive structure formed by one cell, capable of originating a new organism without fusing with another cell

Sporangia

Structure in which spores are formed

Stamen

Element of the male reproductive apparatus of a flower that carries pollen. It is formed by a filament that supports two pollen sacs on its upper part.

Stem

Part of a plant that holds up the leaves or the reproductive structures

Stigma

Upper part of the female reproductive apparatus of a flower. The receptor of pollen, it connects with the ovary.

Storage organ

Part of a plant that consumes sugars or functions to store sugars. Examples are stems, roots, and fruit.

Thallus

Plantlike body of brown seaweed. Also the long, rigid part that holds up the reproductive structures of some fungi.

Thylakoid

Small, flat sac that makes up part of the internal membrane of a chloroplast. Site where solar energy is transformed into chemical energy as part of the process of photosynthesis.

Tissue

Group of identical cells with the same function

Tuber

Modified, thickened underground stem where the plant accumulates reserves of food substances

Vascular

Describes plants with a complex structure and highly organized cells for transporting water and nutrients to all parts of the plant

Xerophyte

Plant that grows in deserts and other dry environments

Xylem

Part of a plant's vascular system. It transports water and minerals from the roots to the rest of the plant.

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PLANTS, ALGAE, AND FUNGI

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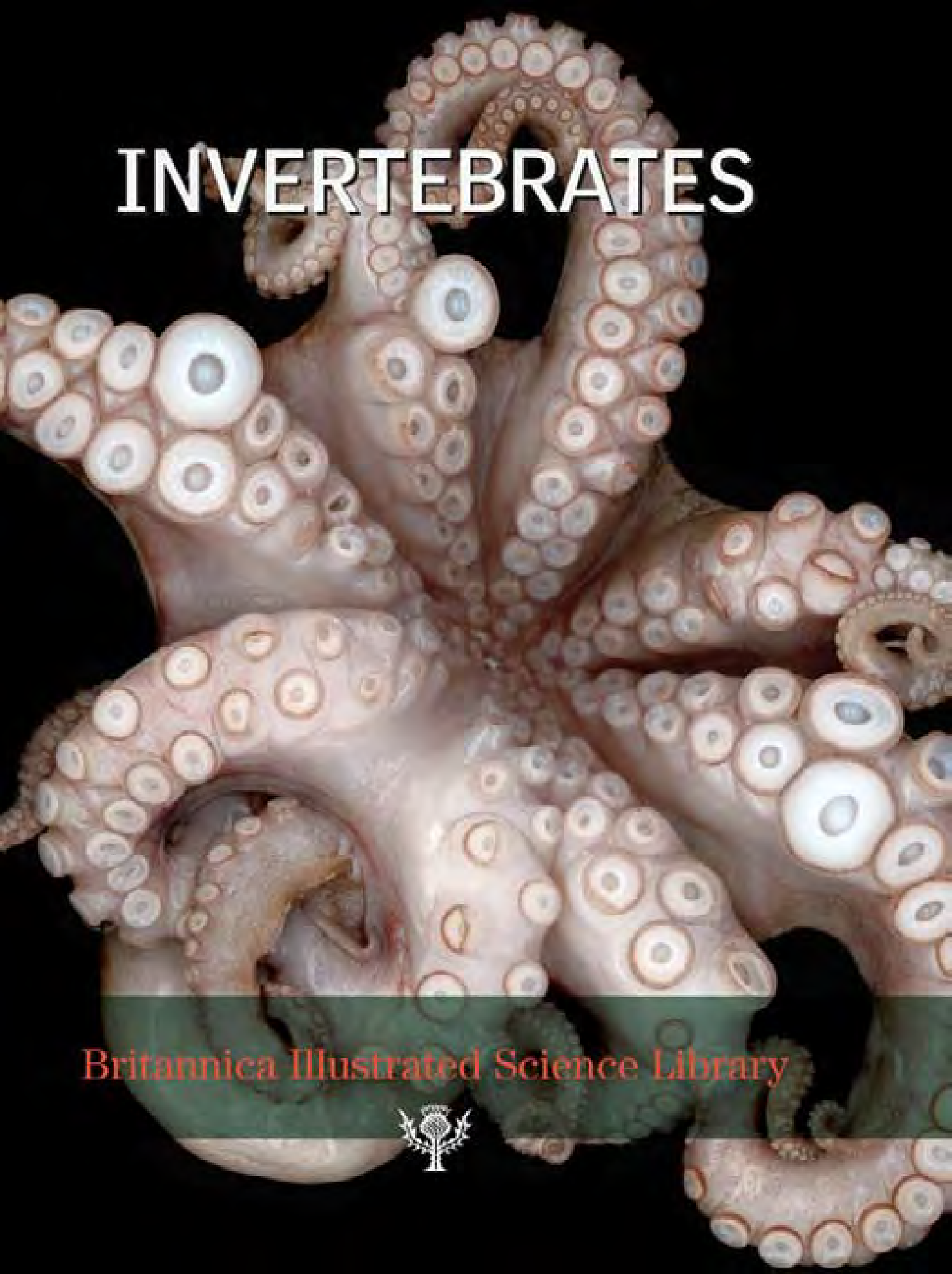

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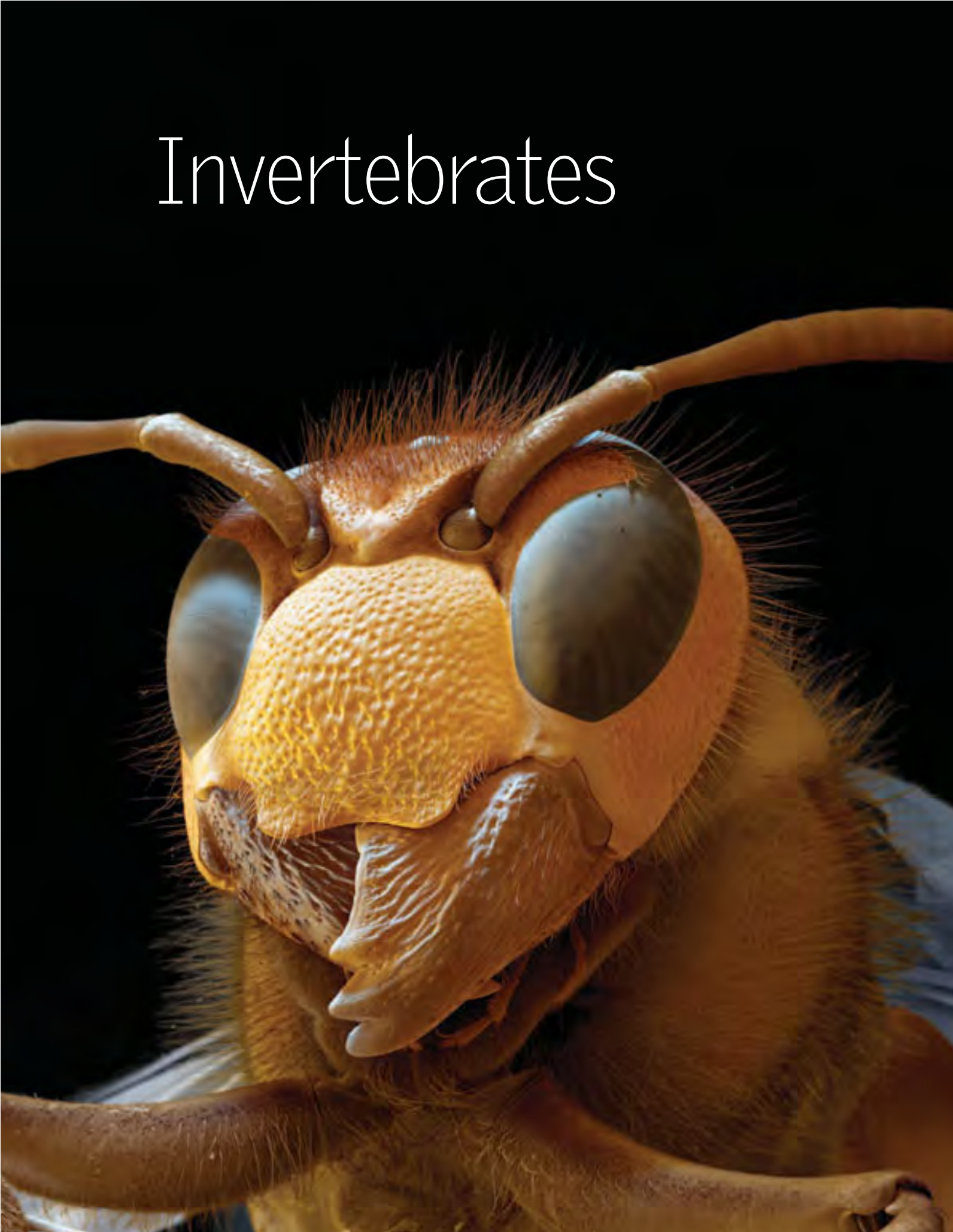

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ARTIFICIAL BEEHIVE
Movable frames allow the beekeeper to remove honey and wax from each comb.

Tiny Creatures

Invertebrates were the first forms of animal life on Earth. They are the most ancient and most numerous of known life-forms. Some, such as worms, sea anemones, and jellyfish, are soft-bodied. Others, such as insects and crustaceans, are hard-bodied. Some, including jellyfish, live in the water and swim freely. However, others, such as corals and anemones, are fixed in one place. This fascinating world of tiny creatures has over 1.5 million known species, with a wide variety of shapes and habits.

Bees are among the most important insects. They process the nectar of flowers to produce honey, a sugary liquid that humans use as a sweetener and nutrient. The nutritive component of honey is pure carbohydrate in the form of simple sugars, which are directly absorbed by the body. This characteristic gives honey its punch as a quick energy source. Edible in its natural state, it can also be used as an ingredient of desserts or to sweeten drinks. Not only bees, however, but also wasps play a fundamental role in the lives of all living beings. Many plants depend on them for pollination of their flowers. Without these insects there would be fewer fruits and vegetables to eat.

Here we show you the inside workings of a beehive. Did you know that one difference between bees and other insects is the organized communities that bees form? Keeping in mind that each artificial honeycomb has about 30,000 inhabitants, there must be a way to keep order, and the bees know by instinct how to do this. The queen, the drones, and the workers know their roles and duties well. They may even die defending the colony, just like ants, who are also true masters of order and productivity. Noteworthy in the world of insects is their high degree of evolutionary development. They are the highest achievers of the animal world. They live all over the planet, need little food to survive, and escape from predators with highly developed means of locomotion. All insects have jointed legs and an external skeleton for protection. In this book you will also be able to admire the beauty of butterflies and the changes they experience throughout their lives, and you will discover the world through the eyes of a fly. Have you heard that, among the 35,000 known species of spiders, only 30 are truly poisonous, and that without these poisonous creatures we would be swimming in a sea of insects? Also interesting are the many kinds of spiderwebs that spiders use for making traps, mating, moving about, and covering their burrows.

We invite you to explore the pages of this fact-filled book, with fascinating photos and intriguing facts about the inner and external lives of the invertebrates that share our world. Mosquitoes, for example, can pierce the skin of mammals and feed on their blood, and flies can eat solid food because their digestive process begins outside their bodies. No athlete can jump like the flea, a tiny, wingless insect that lives on the blood of birds and mammals. We will also tell you about beneficial insects that can be useful to have in your house, and about others that it would be better to control and keep away, because they can transmit sicknesses such as Chagas disease. Just turn the page to find detailed accounts along with carefully selected images that will show you in full detail how some of the smallest creatures on Earth live, change, grow, and communicate. It is well worth it!

Origin and Habitats

ANOMALOCARIS
The largest predator of trilobites in the Cambrian Period, it measured up to 20 inches (0.5 m) long.

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The first life-forms appeared nearly 4 billion years ago. The main groups of organisms with complex cells (eukaryotes) evolved during the Precambrian Period. Fossils found in Australia and Canada show that those invertebrates had soft bodies, quite different from those that exist today. Members of the kingdom Animalia became adapted to many environments, extending from the bottom of the ocean to the highest mountain peaks. We will show you the oldest species and many of the main groups of today: sponges (phylum Porifera); corals, anemones, and jellyfish (phylum Cnidaria); shellfish (phylum Mollusca); sea worms and earthworms (phylum Annelida); insects, spiders, millipedes, and crustaceans (phylum Arthropoda); and starfish and sea urchins (phylum Echinodermata). ●

Traces of Ancient Life

Millions of years ago, our planet was not as we know it today. The continents were arranged differently, and the climate, flora, and fauna were different. How do we know this? We have learned these things by finding and studying fossils, remains of past life-forms that are preserved in both geography and time. The Ediacara, in southern Australia, and the Burgess Shale, in Canada, are two regions with extensive fossil beds of soft-bodied invertebrates. Both areas have shed light on what is known as the Cambrian explosion. ●

Ediacara

This group, called Ediacara fauna, is the oldest known group of multicelled organisms. Found in Precambrian rock, it predates the great Cambrian explosion. Its age is around 600 million years; it contains impressions, or molds, of diverse animal forms conserved in sedimentary rock, without a trace of hard parts. The first such bed was found in southern Australia, in the Ediacara Hills.

600 million years
AGE OF THE FIRST SPECIMENS FOUND

AUSTRALIA
Latitude 35° 15′ S
Longitude 149° 28′ E

The first specimens were found in the Ediacara Hills.

DICKINSONIA SPECIES
Believed to belong to the Cnidarian (coral, jellyfish, anemones) or Annelid (worms) phyla. The largest was 17 inches (43 cm) long.

Mouth

JELLYFISH
Ediacaran

CHARNIA
One of the most widely found fossils of the Ediacaran Period. It is believed to have been related to certain cnidarian colonies.

Burgess Shale

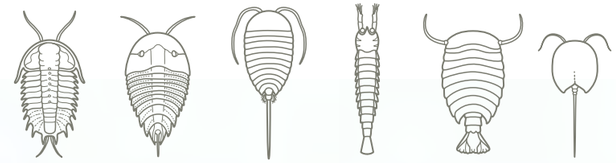
Located in Canada, Burgess Shale is well known for its fossil bed of soft-bodied animals from the Cambrian Period. This bed gives a glimpse of what ocean life was like during the Cambrian Period, with specimens of the four main types of arthropods: trilobites, crustaceans, horseshoe crabs, and Uniramia (the group that includes insects).

540 million years
AGE OF THE FOSSILS FOUND IN THIS BED

CANADA
Latitude 51° 25′ 30″ N
Longitude 116° 30′ 00″ W

This fossil bed is outstanding for the variety of creatures found.

EVOLUTION
Trilobites are the best-known fossilized animals to appear during the Cambrian explosion. The fossil record shows an extraordinary proliferation of life-forms during this stage of life on Earth. From this time on, no new structures of morphological organization appeared. Rather, existing forms evolved and diversified.



Olenoides *Xandarella* *Emeraldella* *Yohoia* *Sidneyia* *Burgessia*

AYSHEAIA
From 0.5 to 2.5 inches (1-6 cm) long.

OPABINIA
From 1.5 to 3 inches (4-7 cm) long.

Mouth

Mouth

CHANCELLORIA
This cylindrical form is thought to have possibly been a sponge.

Mouth

Mouth

ANOMALOCARIS
20 inches (50 cm) long.

Mouth

CANADIA
Estimated to have been between 0.8 and 2.0 inches (2-5 cm) long.

Mouth

Mouth

WIWAXIA
A rare marvel with no known biological relationship to any other life-form.

MARRELLA SPLENDENS
Less than one inch long, this creature is thought to live on the seafloor.

OTTOIA
This priapulid worm could measure up to 3 inches (8 cm) long.

SIZES
The Burgess Shale invertebrates had a wide range of sizes, from microscopic to nearly 7 feet (2 m) long. (Dogs, on the other hand, have a narrower size range; the most common breeds range from 20 to 40 inches [50-100 cm] tall.).

Anomalocaris Dog

20 inches (50 cm)

FOSSILS
Fossils yield clues about life in the past. By comparing fossilized organisms from different periods of the Earth's history with organisms of today, we can deduce how various life-forms have changed over time.

Mouth

Frozen in Time

Fossils give evidence about many different ancient life-forms. Bones, footprints, and other signs of animal and plant life can become fossils as their organic components are replaced by mineral compounds. Many arthropods were trapped in the sap of certain trees. When this sticky substance hardened, it became what is called amber. Amber is very useful for studying processes that gave rise to the diversity of life on Earth.

Value

Amber containing animals that lived millions of years ago is used to make jewelry. Its price depends on the type of organism it contains.

Properties and Characteristics

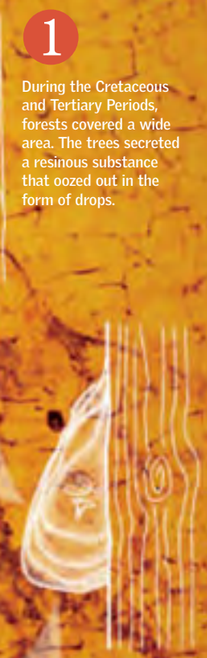
Amber is a material derived from the fossilized resin of certain trees that lived between 144 and 65 million years ago. Over time they were fossilized, forming large, irregular masses within layers of sandstone and slate mixed with clay. Masses of amber range from very small, only a fraction of an inch, to many times longer, up to 20 inches (50 cm) in length, with a hardness of 2 to 3 on the Mohs scale. Amber is composed of carbon, oxygen, and hydrogen.

FOSSIL IN AMBER
Photograph of amber that contains fossil remains from 38 million years ago. This piece is valued at nearly $35,000.

FOSSILIZED ARACHNID
This spider, perfectly conserved thanks to the protection of the amber, enables scientists to make reliable comparisons with genera and species of today.

1

During the Cretaceous and Tertiary Periods, forests covered a wide area. The trees secreted a resinous substance that oozed out in the form of drops.



2

This substance accumulated on tree branches and bark and at the foot of the trunk, trapping all sorts of plants and animals (even toads) that got stuck in the thick resin.

3

The resin insulated the animal from the atmosphere and protected its remains from water and air. As the resin hardened, it gradually formed a protective, pressure-resistant layer. Over time this layer was transformed into what we know today as amber.

Diverse Origins

The color of fossilized amber depends on the type of tree it came from, when it was formed, and the environment where it was fossilized. Amber is usually yellow, although it may come in many shades ranging from orange, red, brown, blue, and green to transparent varieties. Although color is important, amber is classified according to its origin.

Mineral deposit	Origin	Shades
Baltic	Eocene conifers	
Burma	Eocene Burseraceans	
Dominican Republic	Miocene legumes	
Sicily	Miocene Burseraceans	
Romania	Miocene legumes	
Mexico	Miocene legumes	
Canada	Cretaceous conifers	

572° F
(300° C)
The melting point of amber

Ancient Life-Forms

Finding these fossilized creatures enables us to learn about life-forms and environments of the past. The presence of certain fossils can help us to determine what the climate was like millions of years ago and to date rock layers. We know that certain plants and animals lived in specific periods. Their presence or absence can help us determine the age of the rock layer where they are found. Not only did amber preserve plants and animals, but it also trapped air bubbles.

The First Conquest

To be able to live on land, invertebrates developed ways of breathing and moving that were adapted to a land environment. Thus insects, which can walk and fly, have populated land and air environments. Other invertebrates have also become accustomed to life in this element, and they play an important role in land ecosystems.

Who Eats Whom?

The relationships of eating and being eaten that are established among the organisms of an ecosystem are called the food chain. In contrast to plants, whose capacity for photosynthesis gives them the role of food producers, invertebrates occupy various levels in the food chain as food consumers.

THE ORDER OF THE FOOD CHAIN

Fleas

Ladybugs

Spiders

1 **FIRST LEVEL** Invertebrates that eat plants

2 **SECOND LEVEL** Carnivores that eat herbivorous invertebrates

3 **THIRD LEVEL** Larger invertebrates that eat other carnivorous invertebrates

70% OF THE SPECIES THAT LIVE IN TREES ARE INSECTS.

MONARCH BUTTERFLY *Danaus plexippus*

ASIAN TIGER MOSQUITO *Aedes albopictus*

CRAMER'S BLUE MORPHO *Morpho rhetenor*

PRAYING MANTIS *Family Mantidae*

The Most Successful

Beetles (order Coleoptera) are the most prolific and diverse group of the animal kingdom. This is mostly because of their chitinous exoskeletons and highly compact elytras (wing covers), which give each species the hardness, flexibility, texture, or color it needs to adapt to its environment.

OVER **350,000** SPECIES OF BEETLES ARE KNOWN.

COMMON FURNITURE BEETLE *Anobium punctatum*

Tunnels bored by beetles

WASP *Polistes* sp.

FEEDING ON DEAD MATTER

TICK *Boophilus* sp.

SILVERFISH *Lepisma saccharina*

BROWN GARDEN SNAIL *Helix aspersa*

EUROPEAN HORNET *Vespa crabro*

BURYING BEETLE *Nicrophorus investigator*

BLACK VINE WEEVIL *Otiorhynchus sulcatus*

SPIDER *Drassodes* sp.

DESERT MILLIPEDE *Orthoporus ornatus*

CENTIPEDE *Lithobius* sp.

BLOOD-RED ANT (WORKER) *Formica sanguinea*

PILLBUGS *Armadillium* sp.

SILKWORM *Bombyx mori*

CLICK BEETLE *Agriotes lineatus*

EARTHWORM *Lumbricus* sp.

Small Arthropods

Most land- and air-dwelling arthropods have a tracheal respiratory system consisting of highly efficient air tubes that supply oxygen directly to the cells and tissues. The tracheal system makes it possible for these arthropods to maintain a high metabolic rate, but it also tends to limit body size. That is why land-dwelling arthropods are relatively small compared to the rest of the animal kingdom.

Naturally Programmed

The world of air- and land-dwelling invertebrates includes societies, such as those of bees, wasps, and ants (order Hymenoptera). The bees' dances to inform other bees about the location of new food sources, their strict division of labor, or the structure of a spiderweb correspond to patterns of behavior specific to each species. Each individual carries these patterns inscribed within, like a computer program that executes perfectly.

Life Began in the Sea

Invertebrates are not defined by any single common characteristic, but simply by not being vertebrates. Their heterogeneity is most notable in the ocean. Some 3.8 billion years ago, life arose in our planet's oceans. The species that inhabit the ocean waters show greater diversity than those found in other environments. Some forms of animal life, such as corals and sponges, are so simple that they are not able to move about on their own. Others, such as some cephalopods, show great intelligence and skill.

A World Without Insects

Arthropods are the most prolific animals on the planet. But just as insects (hexapods) reign on land, crustaceans have been successful in the water. They breathe through gills, and some, such as krill, are microscopic. Most, however, are larger than insects-mostly because they have no need of complex and costly metamorphosis.

50,000
KNOWN CRUSTACEAN SPECIES
THE VAST MAJORITY LIVE IN THE SEA

CORAL
Acropora sp.
Coral reefs are environments inhabited by thousands of ocean creatures. They make up their own ecosystem.

CARAMOTE PRAWN
Penaeus kerathurus

AMERICAN LOBSTER
Homarus americanus

ANTARCTIC KRILL
Euphausia superba

BROADCLUB CUTTLEFISH
Sepia latimanus

The Largest

The reduced effects of gravity in the water enable the largest invertebrates to live in the sea. Out of the water, octopus and squid-cephalopod mollusks with no rigid structure or joints in their bodies-would not be able to move or hold themselves up, let alone hunt. Perhaps this is why no invertebrates of this size are found on land.

Unique Shapes

Some sea organisms, such as jellyfish, some sponges, and anemones, are very simple. Others, such as sea urchins and starfish (phylum Echinodermata), are more complex. However, all of these life-forms have a body plan called radial symmetry, which, in contrast to bilateral symmetry, is found only in the sea.

RADIAL SYMMETRY

WHITE JELLYFISH
Rhizostoma pulmo

JELLYFISH
Thysanostoma loriferum

COMMON OCTOPUS
Octopus vulgaris
Found up to 30 feet (10 m) deep

66 feet (20 m) length
of the giant squid
Architeuthis dux

BIGFIN REEF SQUID
Sepioteuthis lessoniana
Male and female

RADIANT SEA URCHIN
Astropyga radiata
Defends the crab against predators

URCHIN CRAB
Dorippe frascone
Transports the sea urchin in a form of symbiosis

RED STARFISH
Echinaster sepositus

SEA SLUG
Chromodoris willani

COMMON STARFISH
Asterias rubens

OYSTERS
Crassostrea sp.

BEADLET ANEMONE
Actinia equina

CHRISTMAS TREE WORM
Spirobranchus giganteus

TIGER COWRY
Cypraea tigris

SEA CUCUMBER
Thelenota sp.

Medium and Substance

Gills enable oxygen from the water to enter directly into an animal's circulatory system. Through tiny chambers, they exchange gases with the surrounding water. But the simplest organisms, without digestive tracts, feed by absorbing other substances and trace elements from the water.

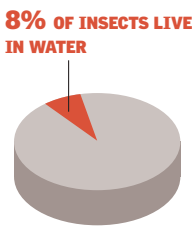
SPONGE
Spongia officinalis
Absorbs nutrients from the water

Teeming Freshwater Environments

In rivers, ponds, lakes, lagoons, and swamps, many invertebrate species are adapted to life in the water but come from other habitats. Thus, water beetles breathe, not with gills, but with spiracles, the way land insects do. This means they must obtain a reserve of air or come to the surface to breathe. Crustaceans have mechanisms that protect them from losing salt in fresh water. With these adaptations, invertebrates make seemingly calm waters the scene of an intense struggle to survive.

One Species, Two Environments

Many species of land- and air-dwelling insects lay their eggs in water. After hatching, the larvae undergo metamorphosis in the water. This fact has enabled certain species to prosper by colonizing more than one environment at once. Not only does the same individual inhabit different environments at different stages of its life, but it also has distinct feeding habits and means of breathing during those stages. That fact keeps adults of the species from competing with the young for food.



On the Border

The areas in and around water and close to the water's surface are the scenes of a battle for survival. Most freshwater insects live in this zone.

EMPEROR DRAGONFLY
Anax imperator
The adults feed on small flying insects that live near plants by the shore of bodies of fresh water.

Molting dragonfly

LIFE CYCLE OF THE COMMON MOSQUITO

4 ADULT
After a few days the pupa's skin splits and the adult mosquito emerges. The adult will live for only a few weeks.

3 PUPAE
The larva molts four times as it grows, finally reaching the pupa stage.

1 EGGS
After feeding on blood, adult females lay 40 to 400 eggs on the surface of the water.

2 LARVAE
After one week, the eggs hatch and the larvae are born.

THE PROCESS LASTS ABOUT ONE MONTH

MAYFLY
Hexagenia sp.

WATER MEASURER
Hydrometra stagnorum

COMMON POND SKATER
Gerris lacustris
Lives in water. It has just the right weight and structure to take advantage of surface tension when the water is calm.

WATER BOATMAN (BACK SWIMMER)
Notonecta glauca

Adapted to the Water

Some water species breathe through air tubes or tracheae. All such organisms had to develop a mechanism or device for providing themselves with air, because tracheae and tracheoles are useless for breathing underwater.

ZOOPLANKTON

GREAT POND SNAIL
Lymnaea stagnalis

DRAGONFLY NYMPH

DIVING BELL SPIDER
Argyroneta aquatica

GREAT DIVING BEETLE
Dytiscus marginalis

WHITE-CLAWED CRAYFISH
Austropotamobius pallipes
Glands on its antennae excrete water and maintain the balance of salts in its body.

CADDISFLY LARVA
Limnephilus sp.

Living Off Others

Some organisms are parasites. They do not obtain their own food; rather, they live at the expense of another species. Although they depend on another animal for sustenance, they avoid doing the other species too much harm. Otherwise, the parasite would have to find a new host.

In Fresh Water

Ocean invertebrates live in an osmotic balance between water and the salts the water contains. Invertebrates that live in estuaries or other places where salt water receives currents of fresh water (euryhaline organisms) must keep the concentration of salts in their bodies constant, even when the salinity of the water changes. In fresh water, with its low concentration of salts, crustaceans developed mechanisms to eliminate water and capture salts actively-that is, their bodies expend energy on these functions. For this reason river crustaceans, unlike sea crustaceans, urinate.

WATER BEETLE LARVA

Most parasitic worms are microscopic in size. The ones shown here are highly magnified.

BLOOD-FLUKES (BILHARZIA)
Schistosoma sp.

TRICHODINA
Trichodina fultoni

MEDICINAL LEECH
Hirudo medicinalis

COPEPOD
Cyclops sp.

The Simplest Life-Forms

THE SIMPLICITY OF THE JELLYFISH
The jellyfish is a very simple animal with a gelatinous consistency and with no respiratory, digestive, or excretory systems. It drifts around in warm ocean waters.

RADIAL SYMMETRY 20-21
SEA CARNIVAL 22-23
AQUATIC 24-25
LEGLESS 26-27
JOINTLESS 28-29
GENERATING ADDED VALUE 30-31
POWERFUL TENTACLES 32-33

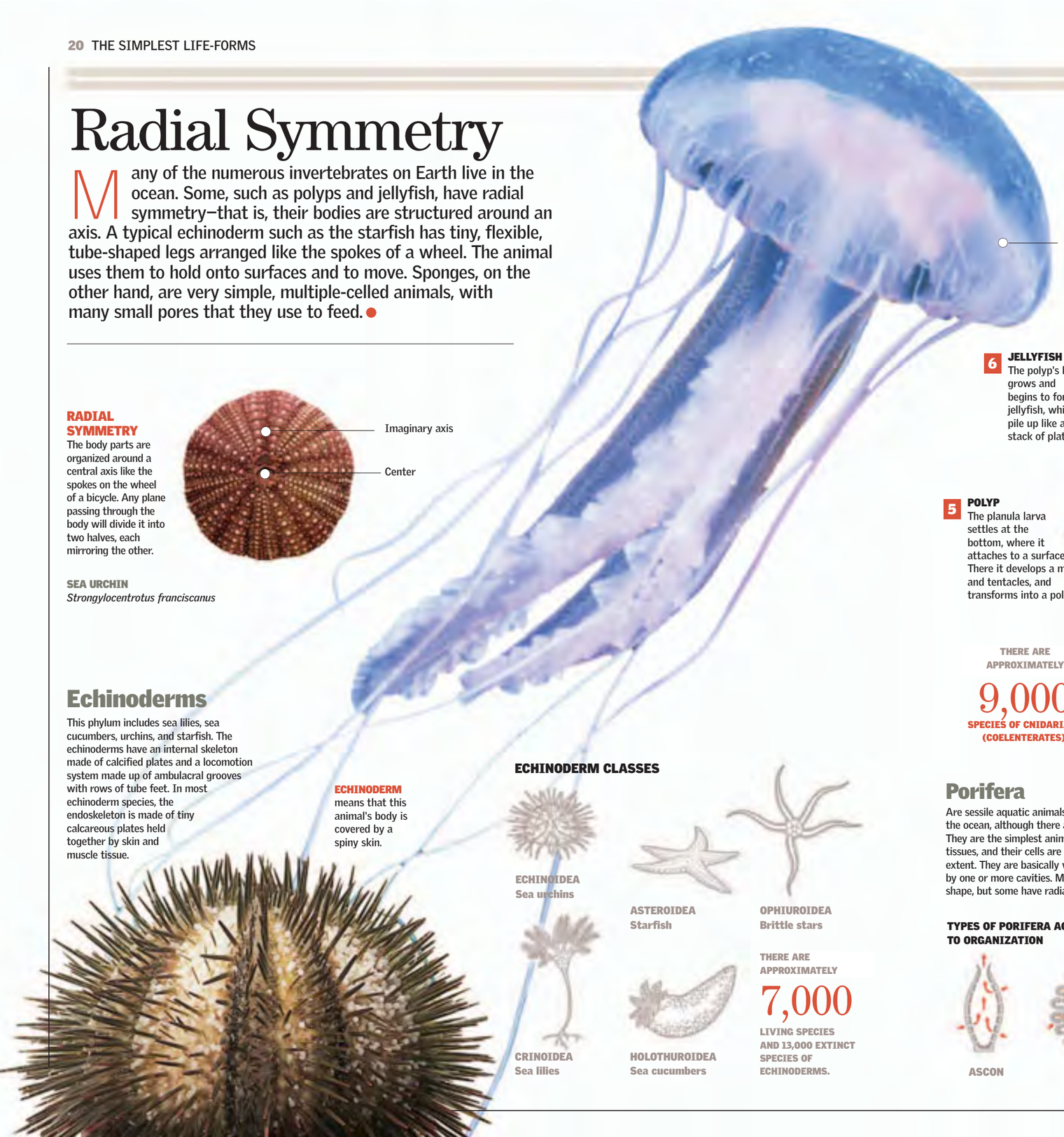
Even though most organisms such as sponges, jellyfish, and sea anemones look like vegetables, they belong to the animal kingdom. Many of these simple invertebrates are unable to move from one place to another; some even lack certain tissues or an entire respiratory or digestive system. Other, more developed species, such as squid and octopus, can move about and have become skilled marine predators. Cephalopods are the most highly evolved mollusks. Their heads have highly developed eyes, a mouth with two horn-like jaws, and tentacles with suckers to trap their prey. Some cephalopods live in deep-sea waters, whereas others stay close to shore. ●

Radial Symmetry

Many of the numerous invertebrates on Earth live in the ocean. Some, such as polyps and jellyfish, have radial symmetry—that is, their bodies are structured around an axis. A typical echinoderm such as the starfish has tiny, flexible, tube-shaped legs arranged like the spokes of a wheel. The animal uses them to hold onto surfaces and to move. Sponges, on the other hand, are very simple, multiple-celled animals, with many small pores that they use to feed.

RADIAL SYMMETRY
The body parts are organized around a central axis like the spokes on the wheel of a bicycle. Any plane passing through the body will divide it into two halves, each mirroring the other.

SEA URCHIN
Strongylocentrotus franciscanus



JELLYFISH
Pelagia noctiluca

Cnidarians

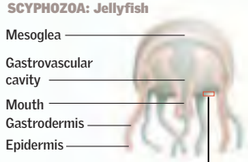
Cnidarians are a group of aquatic animals that includes jellyfish, hydras, sea anemones, and corals. Their cells are organized in true tissues. They have specialized cells called cnidoblasts for stinging prey and for defense. Two basic types of cnidarians are polyps and jellyfish.

CLASSIFICATION

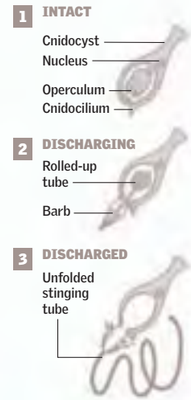
HYDROZOA: Asexual polyp

ANTHOZOA: Sea anemones and corals

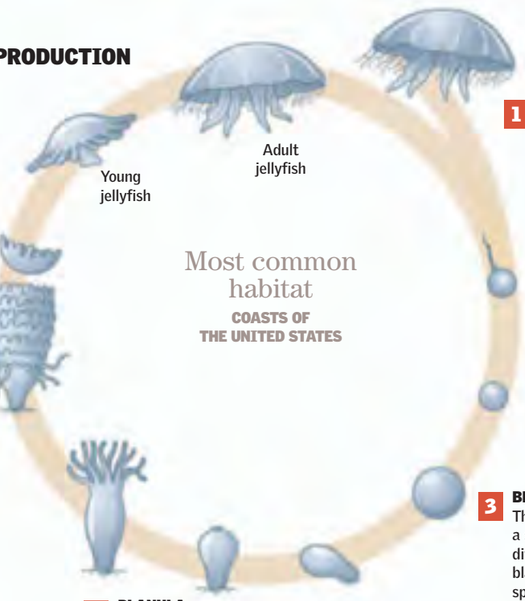
SCYPHOZOA: Jellyfish



STINGING CELL
Used for defense



REPRODUCTION



1 GAMETES
Adult jellyfish produce sperm and egg cells during meiosis and then release them.

2 FERTILIZATION
Fertilization takes place in the waters near the jellyfish, resulting in a zygote.

3 BLASTULA
The zygote, after a series of cell divisions, becomes a blastula, or hollow sphere, of cells.

4 PLANULA
The blastula lengthens and becomes a ciliated larva called a planula.

5 POLYP
The planula larva settles at the bottom, where it attaches to a surface. There it develops a mouth and tentacles, and transforms into a polyp.

6 JELLYFISH
The polyp's body grows and begins to form jellyfish, which pile up like a stack of plates.

THERE ARE APPROXIMATELY
9,000
SPECIES OF CNIDARIANS (COELENTERATES).

Echinoderms

This phylum includes sea lilies, sea cucumbers, urchins, and starfish. The echinoderms have an internal skeleton made of calcified plates and a locomotion system made up of ambulacral grooves with rows of tube feet. In most echinoderm species, the endoskeleton is made of tiny calcareous plates held together by skin and muscle tissue.

ECHINODERM
means that this animal's body is covered by a spiny skin.

ECHINODERM CLASSES

THERE ARE APPROXIMATELY
7,000
LIVING SPECIES AND 13,000 EXTINCT SPECIES OF ECHINODERMS.

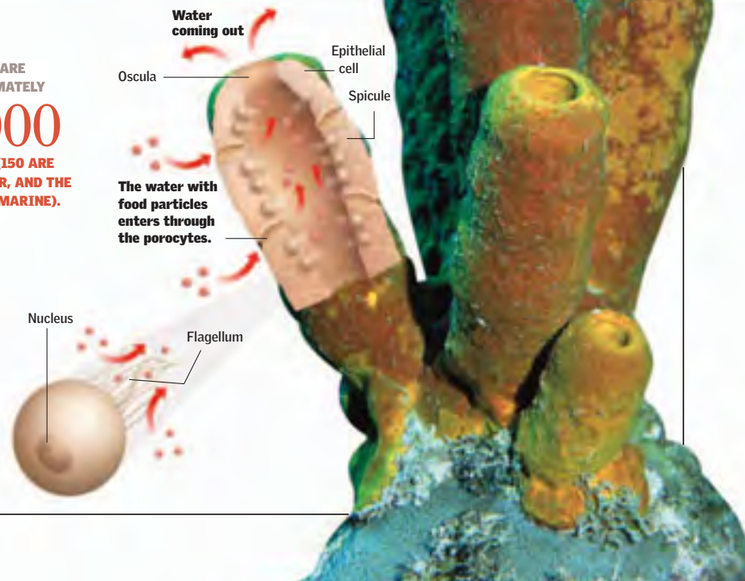
Porifera

Are sessile aquatic animals. Most live at the bottom of the ocean, although there are some freshwater species. They are the simplest animals, lacking organs or true tissues, and their cells are independent to a certain extent. They are basically water-filtering bodies formed by one or more cavities. Most porifera have no definite shape, but some have radial symmetry.

THERE ARE APPROXIMATELY
5,000
SPECIES (150 ARE FRESHWATER, AND THE REST ARE MARINE).

TYPES OF PORIFERA ACCORDING TO ORGANIZATION

→ Direction of water flow



Sea Carnival

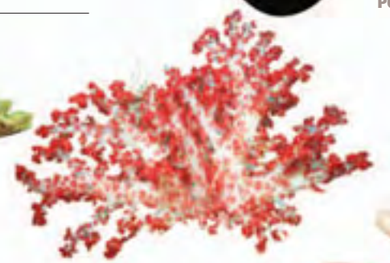
Corals and anemones, together with jellyfish, make up the phylum Cnidaria. Some characteristics they share are their bright colors, tentacles that secrete stinging substances, and a digestive system with a common opening for ingestion and excretion—the simplest digestive system in the animal kingdom. All of these organisms are quite simple. Corals generally form colonies, large groups of small polyps that stay practically immobile and feed on microorganisms brought to them by water currents. Sea anemones, on the other hand, are solitary and can trap prey despite their limited locomotion. ●

CORAL POLYP

Coral Reefs

Corals are small polyps with tentacles that grow at their base throughout their life, generating a calcareous exoskeleton. This skeleton forms masses, or branches. Most corals grow in colonies; the skeletons form huge calcareous masses called reefs. Corals live mostly in warm, shallow ocean waters. Their reproduction can be both sexual and asexual, by division or by gemmation. They feed on plankton.

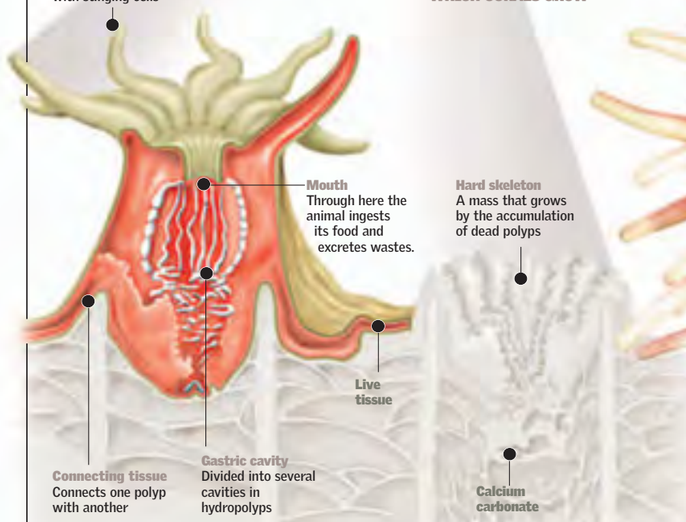
HARD CORALS
grow over the surface of the lime-bearing substrate.



SOFT CORALS
branch out; their skeleton is not lime-based but horn-like and flexible.

CORAL WALLS
Even though some coral walls live alone, most form colonies that can grow upward at up to 3 feet (1 m) every year.

100 feet (30 m)
THE MOST COMMON DEPTH AT WHICH CORALS GROW

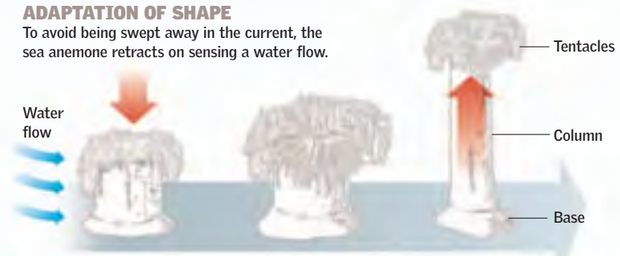


Beautiful but Deadly

Beautiful for their shapes and colors that vary even within the same species, and dangerous for the poison they use to sting both victims and predators, sea anemones live in almost all marine latitudes, and at varying depths. Tropical marine anemones can measure up to 3 feet (1 m). They have a basal disc, which allows some species to attach to rocks, and others to slither, and still others to penetrate the seafloor. They trap live prey, even fish, with the many tentacles around their mouths.

9,000
THE NUMBER OF CNIDARIAN SPECIES IN THE WORLD

ADAPTATION OF SHAPE
To avoid being swept away in the current, the sea anemone retracts on sensing a water flow.

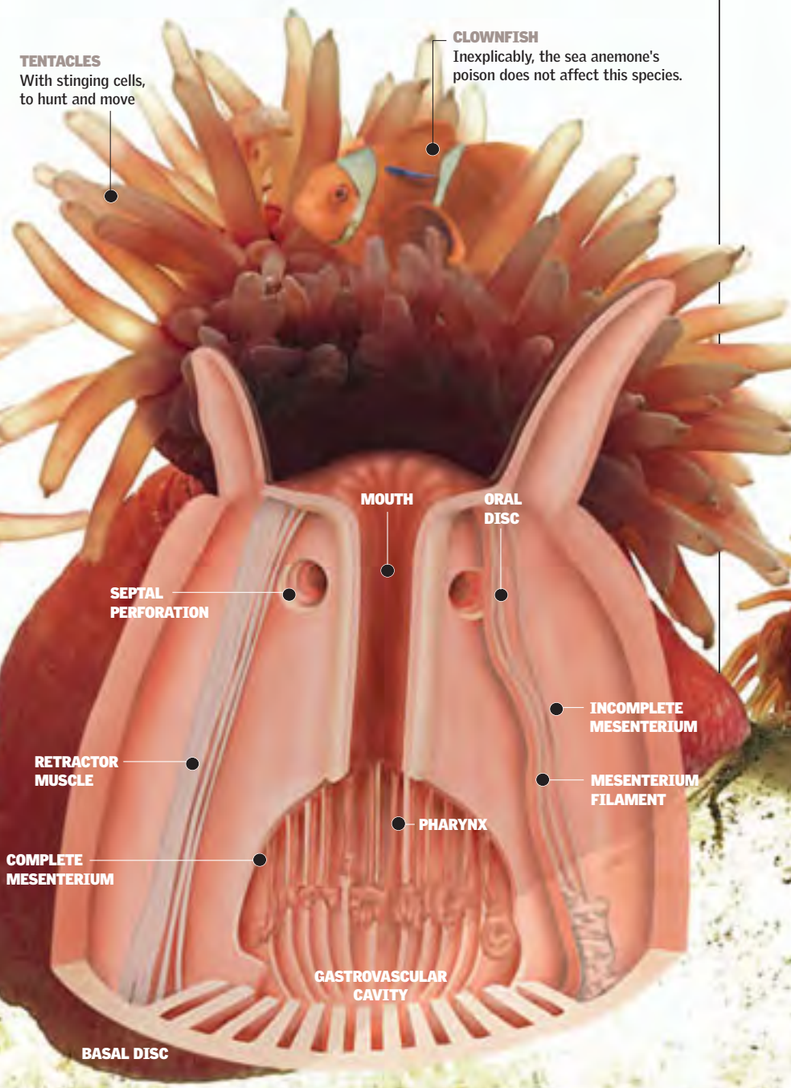


CONTRACTION
The sea anemone reduces its size.

DISTENSION
By means of the retractor muscle

EXTENSION
When the water is calm

SEA ANEMONE
Any vertical plane passing through its center divides it into two equal parts.



Aquatic

Echinoderms (phylum Echinodermata) are one of the best-known groups of marine invertebrates. Sea urchins and starfish, despite their apparent differences, are part of the same group and share characteristics such as five-radial symmetry. This phylum has an aquatic vascular system with many ambulacral grooves with tube feet, which it uses for locomotion, capturing prey, and breathing. In addition, it has an internal skeleton made of calcareous plates. These creatures lack a brain or eyes, so they use photoreceptors to sense movement.

Defense System

Characterized by complete five-sided symmetry, sea urchins' bodies are covered by several mobile spines that give them a dangerous appearance. The spines are spread evenly throughout the skeleton's surface and are used as a defense system.

BARB
Used for defense

6,000
THE NUMBER OF ECHINODERM SPECIES

SEA URCHIN
Astropyga radiata

SPINES
There are two varieties of spines: larger primary spines and shorter secondary spines. They are usually cylindrical with a narrowed tip.

PYLORIC CONDUIT
Moves the water that ends at the pyloric cecum, which functions as a digestive gland

STOMACH

ESOPHAGUS

STARFISH
Archaster typicus

570 million years
THE LENGTH OF TIME ECHINODERMS HAVE BEEN IN EXISTENCE

SKIN
The underside is covered by spines.

RADIAL CANAL
The water passes and circulates to the sacs.

SAC
Fills with water, expands, and clings to the surface

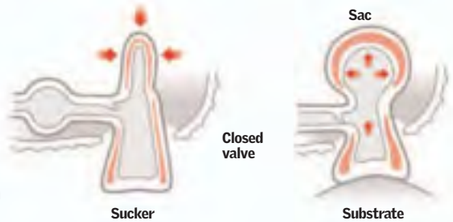
MOUTH
Surrounds the food and breaks it down with stomach juices

Ambulacral Grooves

These structures are hollow cylinders with thick walls that straighten and move when a starfish injects water into certain vesicles in its body. The ambulacral grooves end in suckers that the animal uses to attach itself to objects, enabling it to move at surprising speed. These sensitive feet shrink if touched abruptly, hiding behind a rim of rigid spines that protect them from harm.

Suction

The sac contracts and puts pressure on the ambulacral groove. The muscles tense and force the water back into the sac, causing suction between the groove and the surface with which it makes contact.



Stages of Movement

1 When the sac muscles contract, they force the liquid to pass to the ambulacral groove, which lengthens and makes contact with an adjacent surface, or substrate.

2 The area near the sucker secretes an adhesive substance that helps keep it attached to the surface. The lateral muscles in the groove contract, and the liquid returns to the sac for locomotion.

3 The muscles can make the tube feet move to either side, and the coordinated movement of all the feet in one direction causes the starfish to advance.

Legless

Worms are invertebrates with long, soft bodies and no legs. They are classified into three phyla. Flatworms are the simplest type; most are parasites, although some are free-living. Nematodes have a cylindrical body with a hard outer surface. Segmented worms are more complex; they include leeches, earthworms, and sea worms. Many species have an impact on plants, animals, and humans. ●

Classes of Worms

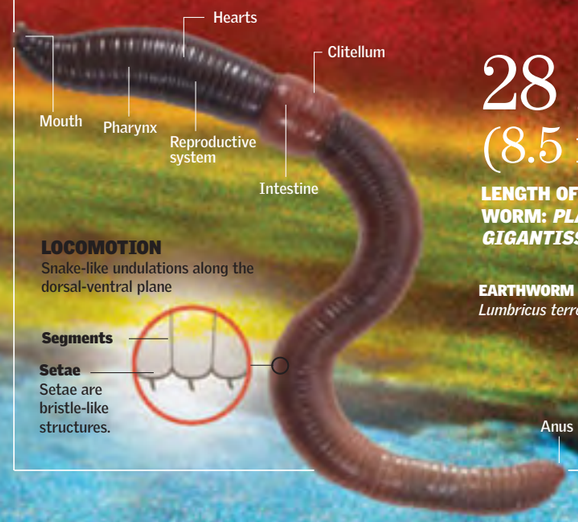
PLATYHELMINTHES **NEMATODA** **ANNELIDA**

Movement Guided by Light

Flatworms have eyespots, or light-sensitive eyes, on the front end of their bodies. When exposed to excessive light, the eyes withdraw and remain immobile.

Digestive System

In annelid worms, the digestive system extends in a straight line from the oral opening to the anus. It includes the mouth, muscular pharynx, esophagus, crop, gizzard, and intestine.



WORM
Nematode enoplida

EPIDERMIS

PROBOSCIS
Partly folded inward

HOOKS
Hold the worm in place

28 feet
(8.5 m)

LENGTH OF THE LONGEST WORM: *PLACENTONEMA GIGANTISSIMUM*

EARTHWORM
Lumbricus terrestris

FOOD
Bacteria and organic wastes

LEMNISCI
Food storage

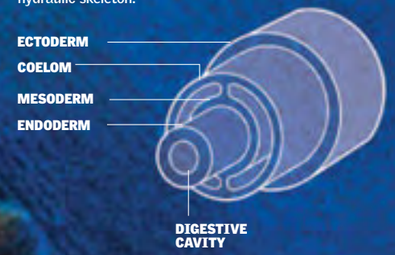
TISSUE
Fibrous and elastic

NECK
Retracts and remains hidden

SPINES
Pierce the wall of the host

Tissues

are formed in layers and are based on the presence of internal cavities. This annelid has three layers and one cavity, the coelom, which carries fluids through the body like a hydraulic skeleton.



AT LEAST
100,000
KNOWN WORM SPECIES

Reproduction

Flatworms and annelids are usually hermaphrodites; nematodes usually have separate sexes. In some cases the worm splits into two, resulting in two new worms.

Jointless

The body of most mollusks is soft, extremely flexible, and without joints, yet has a large and very hard shell. Most mollusks live in the ocean, but they are also found in lakes and land environments. All modern mollusks have bilateral symmetry, one cephalopod foot with sensory organs and locomotion, a visceral mass, and a covering, called the mantel, that secretes the shell. Mollusks also have a very peculiar mouth structure called a radula.

Gastropods

These mollusks are characterized by their large ventral foot, whose wave-like motions are used to move from place to place. The group comprises snails and slugs, and they can live on land, in the ocean, and in fresh water. When these animals have a shell, it is a single spiral-shaped piece, and the extreme flexibility of the rest of the body allows the gastropod to draw itself up completely within the shell. Gastropods have eyes and one or two pairs of tentacles on their head.

BROWN GARDEN SNAIL
Helix aspersa

DIGESTIVE GLAND
INTESTINE
LUNG
GONAD
KIDNEY
HEART
SALIVARY GLAND
ESOPHAGUS
FEMALE SEXUAL ORGAN
RADULA

PROSOBRANCHIA
This mollusk subclass mainly includes marine animals. Some have mother-of-pearl on the inside of their shell, whereas others have a substance similar to porcelain.

LUNGED
Snails, land slugs, and freshwater slugs have lungs, and their lung sacs allow them to breathe oxygen in the atmosphere.

OPISTHOBRANCHIA
are sea slugs, which are characterized by having a very small shell or no shell at all.

BENDING OF THE SNAIL
In snails, bending is a very special phenomenon that moves the cavity of the mantle from the rear toward the front of the body. The visceral organs rotate 180 degrees, and the digestive tube and the nervous connections cross in a figure eight.

Gills
Nervous system
Digestive tract

SEA ANGEL
Candida sp.

COMMON CUTTLEFISH
Sepia officinalis

Bivalves

Mollusks with a shell divided into two halves. The two parts of the shell are joined by an elastic ligament that opens the shell, adductor muscles that close the shell, and the umbo, a system of ridges that helps the shell shut together. Almost all bivalves feed on microorganisms. Some bury themselves in the wet sand, digging small tunnels that let in water and food. The tunnels can be from a fraction of an inch long to over a yard long.

SCALLOP
Pecten jacobaeus

Cockle
Tellin
Razor clam
Otter shell

LAMELLIBRANCHIATA
include most bivalves. They use gills to breathe and to feed. They have no differentiated head, eyes, or extremities. They can grow up to 5 inches (13 cm) long, and they rest on the ocean floor.

GREEN MUSSEL
Perna viridis

PROTOBRANCHIA
This class includes bivalves with a split lower foot, called a sole. Bivalves use their gills only to breathe. This subclass includes small bivalves 0.5 inch (13 mm) wide, called nutclams (*Nucula nitidosa*).

Under the Sand

Many mollusks live buried under the sand in order to hide from predators and the effects of waves, wind, and sudden changes in temperature.

100,000
THE NUMBER OF LIVING MOLLUSK SPECIES; AS MANY MORE HAVE BECOME EXTINCT

Cephalopods

Cuttlefish, octopus, squid, and nautilus are called cephalopods because their extremities, or tentacles, are attached directly to their heads. These predators are adapted to life in the oceans, and they have quite complex nervous, sensory, and motion systems. Their tentacles surround their mouths, which have a radula and a powerful beak. Cephalopods can be 0.4 inch (1 cm) long to several yards long.

COLEOIDEA
Cephalopods of this class have a very small internal shell, or none at all, and only two gills. Except for the nautilus, this class includes all cephalopods alive today—octopus, cuttlefish, and squid.

NAUTILOIDEA
This subclass populated the oceans of the Paleozoic and Mesozoic periods, but today only one genus—Nautilus—survives. A nautilus has an outer shell, four gills, and ten tentacles. Its shell is made from calcium, is spiral in shape, and is divided into chambers.

NAUTILUS
Nautilus sp.

Generating Added Value

Bivalves are sought after and cultivated for their pearls. Pearls are said to be the queen of gems, because they were discovered over 4,000 years ago and were used as important symbols in many ancient cultures. In spite of their high price, pearls start out as a nuisance for the animal that creates them, which could be an oyster, a clam, or a mussel. Oysters produce the most valuable pearls, which are noted for their luster.

Pearl Formation

Occasionally grains of sand or parasites accidentally become lodged in an oyster's body and cannot escape. To relieve the annoyance, the oyster begins a defensive action and secretes a smooth, hard, crystalline substance called nacre around the object. Cultured pearls are formed from particles that are intentionally inserted into an oyster.

1

INCUBATION
Pearl cultivation began in Japan. It consists of inserting into the body of a live oyster a small, round particle made from the shell of a freshwater bivalve. The oyster secretes mother-of-pearl substances from a gland in its liver to cover the object, and the pearl begins to grow.

A Introduction of foreign body

Grain of sand

B The oyster secretes nacre to cover it.

Tongue

2

GROWTH OF THE PEARL
New, uniform layers are constantly added to the pearl, and the cultivator leaves the pearl in place until it reaches the required diameter and quality. During the process, humans intervene only to provide the oysters in farms with the right temperature, water currents, and cleanliness to favor the growth of pearls.

3 to 8 years
TIME IT TAKES FOR A PEARL TO GROW

Organic layer

Aragonite crystal

LAYERS OF NACRE ON THE PEARL

LAYERS OF NACRE ON THE SHELL

Oysters

Tied with ropes

HANGING OYSTERS
These oysters are suspended from bamboo rafts in areas with abundant plankton.

Types of pearls

They can be round or elongated like a grain of rice.

NATURAL PEARL

CULTURED PEARLS

SHELL
Composed of two pieces or valves

INNER SURFACE OF THE SHELL
Sensory tentacles enable the oyster to detect light and darkness.

MANTLE FOLD
surrounds the mantle and controls the flow of water.

DIGESTIVE GLAND
Its cells absorb and digest food particles.

HINGE LIGAMENT
joins the two valves at their upper part.

TENTACLES
have sensory organs.

FOOT
Seldom used; the oyster prefers to swim rather than dig.

PALPS
select the food.

PEARL
Surrounded by nacre

GILLS
absorb oxygen from the water.

MUSCLE
A fiber keeps the shell closed.

3 HARVEST
Cultured pearls make up 95 percent of the pearls currently sold. About 500 million pearls are produced every year. However, pearl farming is a demanding and difficult business because of the nature of pearl oysters: out of 100 oysters cultivated, only 30 will be harvested.

2%
OF THE HARVEST WILL YIELD PERFECT PEARLS.

OYSTERS
Rough

MUSSELS
Smooth

CLAMS
Prickly

Pearl Producers

The number of pearl cultivators is estimated at nearly 5,000. Japan is the main producer.

COMMON EUROPEAN OYSTER
Ostrea edulis

Powerful Tentacles

The eight-tentacled octopus is one of the few large ocean cephalopods to live in deep water. It is usually found on the rocky or sandy bottoms of shallow waters near the mouths of rivers. It generally moves slowly, sometimes moving in brief spurts, but it can reach great speeds when hunting or fleeing. Some are quite intelligent, having highly evolved brains.

Masters of Color

For the octopus, taking on the color of the ocean floor is a camouflage strategy to hide from its prey. In deeper waters, another tactic is to become luminescent to attract the prey. But when the octopus changes colors while doing a certain dance, it is trying to attract the opposite sex.

4 miles per hour (6 km/h)

Maximum speed of a fleeing octopus. Its speed is comparable to that of a fast-walking human.

EYES
Are located on the head. The octopus's sense of sight is exceptionally well developed.

SKIN
The skin is a highly elastic membrane that completely covers the octopus.

HEAD
The head compresses and expands, depending on the octopus's breathing and movements. The head contains the brain but without a rigid protective structure.

TENTACLES
All eight tentacles have the same length. In the male, one tentacle functions as a genital organ.

Speedy Escape

The flow of water into and out of the funnel is regulated by alternately contracting and relaxing ring-shaped muscles and long muscles. By regulating the force at which the water is expelled, the octopus can flee at high speed through a kind of jet propulsion. The octopus moves in the direction its head is pointing, with its tentacles outstretched.

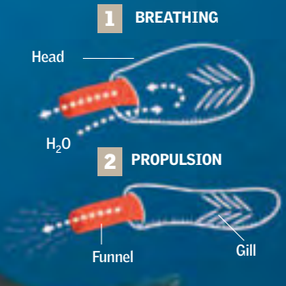
When the ring-shaped muscles contract, they expel a jet of water that propels the octopus backward.

The ring-shaped muscles relax, and the long muscles contract. Water enters.

SELF-DEFENSE WITH INK
A gland located near the anus contracts when the octopus senses danger, expelling a fluid that creates a dark cloud in the water.

The Funnel

The funnel is the exit from the octopus's respiratory cavity. It is also extremely important for the creature's movement. The gills, inside the mantle, absorb oxygen from the water. When the cavity fills, the gills exchange oxygen for carbon dioxide to be emptied from the cavity.



Attack

To attack, the octopus points its funnel in the direction opposite to its motion. The common octopus (*Octopus vulgaris*), a species that can grow up to 40 inches (1 m) long and inhabits the Mediterranean Sea and North Atlantic Ocean, moves among the rocks on the seafloor, preferably at night. It surprises its prey and makes skillful use of its tentacles and jaws, which can rotate.

The funnel muscles can act as a mechanism for fleeing. Rather than directing the funnel forward, though, the octopus directs it to advance toward its prey.

The tentacles stretch forward and outward as the octopus advances.

Using the wide area at the base of its tentacles, it envelops the prey.

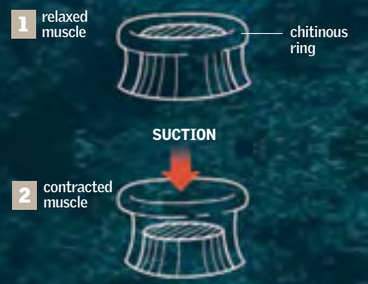
MOUTH
The mouth of an octopus has hard, chitin-like jaws for breaking shells.

Large Predators

Depending on its size, an octopus (like other large cephalopods such as the nautilus, cuttlefish, and squid) is carnivorous and eats both fish and other invertebrates: mollusks and crustaceans, especially crabs. It secretes a venom with its saliva to finish killing the prey before swallowing it.

Grasping Ability

An octopus often crawls among the rocks. Using the system of suckers, or adhesive discs, on its tentacles, an octopus clings to the seafloor or supports itself by attaching the suckers to the surfaces it encounters. By grasping with its forward tentacles, it can drag the rest of its body in that direction.



MUSCLES
Powerful and versatile, with self-controlled movements, an octopus can move the entire weight of its body.

SUCKERS
Arranged in two rows on the lower surfaces for clinging to rocks and for grasping prey.

Crustaceans and Arachnids

COLORFUL ARACHNID
Some species of the family Trombidiidae catch our attention because of their intense red color and the velvet-like appearance of their hair.

COLORFUL ARMOR 36-37
CHANGING OUTFITS 38-39
SHARP FRONT LEGS 40-41
IN THE MIDDLE OF THE CHAIN 42-43
A SPECIAL FAMILY 44-45
QUALITY SILK 46-47
SIXTH SENSE 48-48
POISONOUS STING 50-51

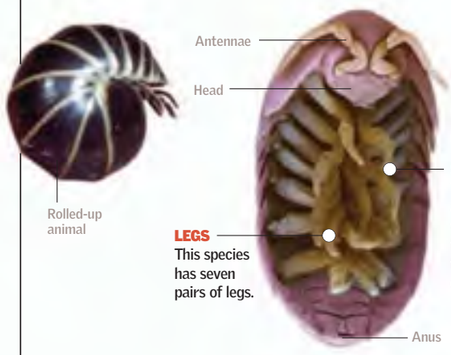
Spiders, snakes, ticks, and mites all belong to the same class, Arachnida. They are covered with sensory hairs so tiny that they cannot be seen by the naked eye. In Greek mythology, Arachne was a woman who challenged the goddess Athena to weave faster than she herself could. This angered the goddess, who turned Arachne into a spider, forcing her to weave forever. That is where these creatures get their name. Within the world of crustaceans, well-known animals such as the shrimp, lobster, and crab are also discussed in this chapter. You will find details about their anatomy, their differences and similarities, and the way in which they live that will surprise you. Some species breathe through gills and also breathe through their skin. ●

Colorful Armor

Even though they inhabit all known environments, crustaceans are most closely identified with the aquatic environment. That environment is where they were transformed into arthropods with the most evolutionary success. Their bodies are divided into three parts: the cephalothorax, with antennae and strong mandibles; the abdomen, or pleon; and the back (telson). Some crustaceans are very small: sea lice, for instance, are no larger than one hundredth of an inch (a quarter of a millimeter). The Japanese spider crab, on the other hand, is more than 9 feet (3 m) long with outstretched legs, as it has legs in both the abdomen and the thorax in addition to two pairs of antennae.

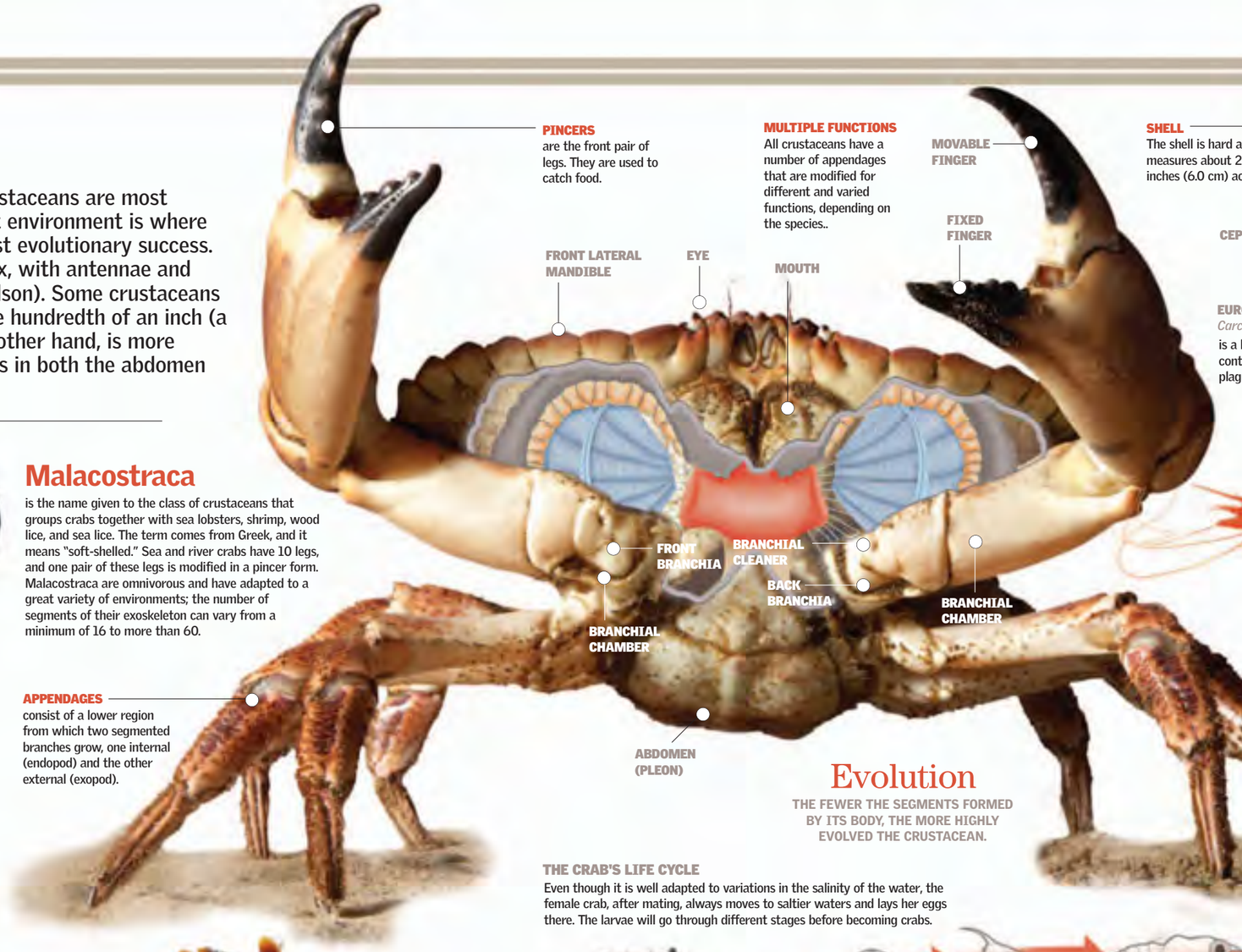
Wood Louse
(Armadillidium vulgare)

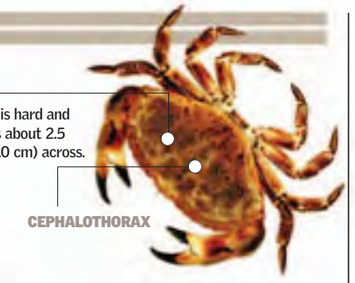
This invertebrate, belonging to the order *Isopoda*, is one of the few terrestrial crustaceans, and it is probably the one best adapted to life outside the water. When it feels threatened, it rolls itself up, leaving only its exoskeleton exposed. Even though it can reproduce and develop away from the water, it breathes through gills. The gills are found in its abdominal appendages and for this reason must be kept at specific humidity levels. That is also why the wood louse seeks dark and humid environments, such as under rocks, on dead or fallen leaves, and in fallen tree trunks.



Malacostraca

is the name given to the class of crustaceans that groups crabs together with sea lobsters, shrimp, wood lice, and sea lice. The term comes from Greek, and it means "soft-shelled." Sea and river crabs have 10 legs, and one pair of these legs is modified in a pincer form. Malacostraca are omnivorous and have adapted to a great variety of environments; the number of segments of their exoskeleton can vary from a minimum of 16 to more than 60.



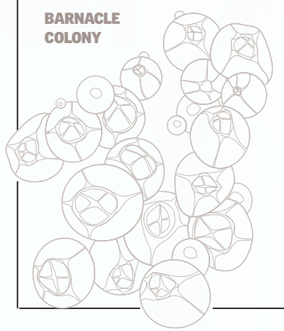


EUROPEAN GREEN CRAB
Carcinus maenas
is a littoral crab that lives on most continents and that has become a plague. It comes in a variety of colors.

SHRIMP AND CRABS
Macrobrachium sp.
The prawn is a 10-legged crustacean that lives in deep waters and is able to withstand great variations in the salinity of its living environment.

THE PACIFIC SPIDER CRAB CAN WEIGH UP TO
45 pounds (20 kg).

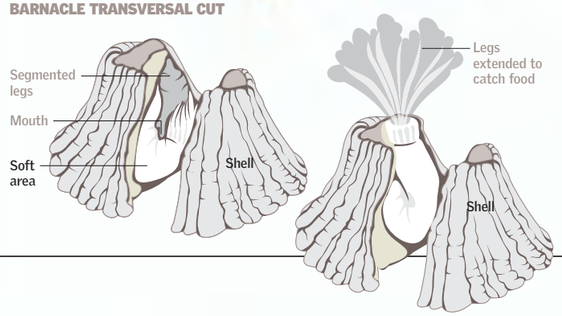
BARNACLE COLONY



Together Forever

At birth, barnacles *(Pollicipes cornucopia)* are microscopic larvae that travel through the sea until they reach a rocky coast. Then they attach themselves to the shore by means of a stalk, which they develop by the modification of their antennae, and then form a shell. Once they are attached, they remain in one spot for the rest of their lives, absorbing food from the water. Barnacles are edible.

BARNACLE TRANSVERSAL CUT

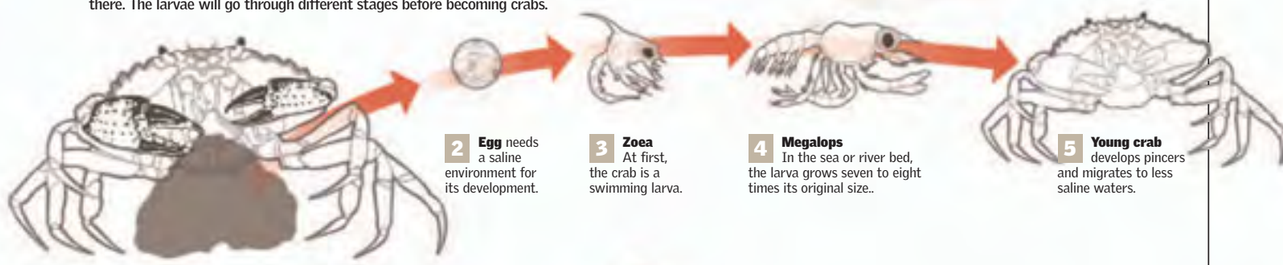


Evolution

THE FEWER THE SEGMENTS FORMED BY ITS BODY, THE MORE HIGHLY EVOLVED THE CRUSTACEAN.

THE CRAB'S LIFE CYCLE

Even though it is well adapted to variations in the salinity of the water, the female crab, after mating, always moves to saltier waters and lays her eggs there. The larvae will go through different stages before becoming crabs.



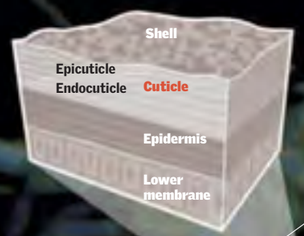
Copepoda

are tiny crustaceans that form part of plankton. Copepoda play a very important ecological role because they are a source of food for many marine animals. There are more than 10,000 species of copepoda. Most are marine species, though there are also some freshwater species. The majority measure between 0.02 and 0.1 inch (0.5-2 mm) long; the smallest ones *(Sphaeronellopsis monothrix)* reach only 0.004 inch (0.11 mm) in length, and the largest *(Pennella balaenopterae)* are 13 inches (32 cm) long.

Changing Outfits

The lobster belongs to the crustaceans, which are characterized by, among other things, an exoskeleton that supports and protects the body of the animal. The exoskeleton has both advantages and disadvantages. The stiffness of the structure prevents growth, which is why the animal grows only when the shell is renewed. This process is called molting. During molting the layers of the new cuticle harden, and minerals and materials from the old exoskeleton are reabsorbed to create a new exoskeleton.

EXOSKELETON
is made of a substance called chitin, which is strengthened by calcium salts. In the exoskeleton molting process, the new layers are formed in the cuticle; they then detach from the epidermis and form a new shell. This process uses a large amount of metabolic energy.



SEGMENTED ABDOMEN
The lobster is made of segments with appendages that give its body its hardness.

LOBSTER
Palinuridae argus

CEPHALOTHORAX
is formed by the abdomen and the fused segments of the head and the thorax, all of which are covered by the shell.

MOVABLE EYE

ANTENNULE

ANTENNAE

PINCER-SHAPED LEG

A LOBSTER CAN LIVE 100 years AND NOT STOP GROWING IN ALL THAT TIME.

NEW ARTICULATED SEGMENT

WALKING LEGS
Five pairs of legs, of which one or more pairs are modified into pincers.

THE LOBSTER MOLTS once a year.

TELSON SEGMENT

DOLPHIN-LIKE TAIL
The tail is used for swimming. The bending of the tail and the abdomen propel the lobster backward and forward.

NEW TAIL SEGMENT

Chitinous Exoskeleton

The hard pincers help the lobster get food, and the segmented body allows for movement. However, the exoskeleton is a disadvantage in small places, because it cannot change shape. Even though the exoskeleton protects the lobster from abrasive contact, it can harm it once it breaks, because the fissure will not mend until the next molting.

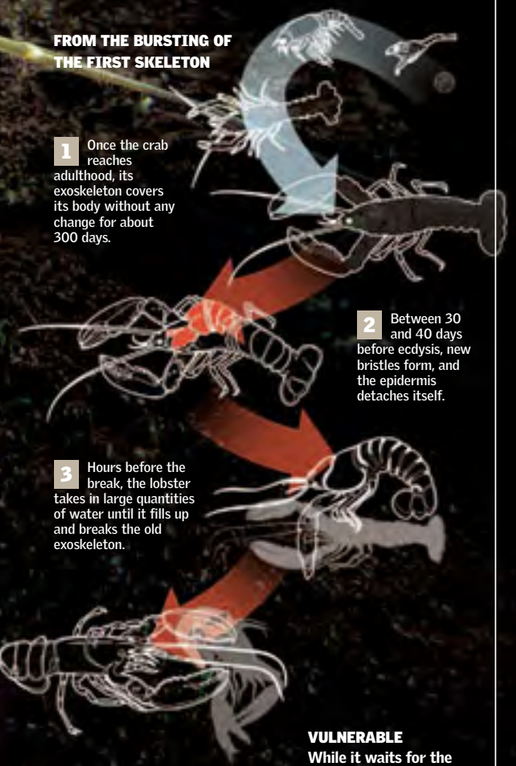
COLOR
Its color varies from gray to green and yellow, including even shadings of red and black.

HERMIT CRAB
Dardanus arrosor

Molting of the Exoskeleton

The presence of the stiff exoskeleton means that crustacean growth takes place during the molting cycle. This phenomenon occurs cyclically and frequently in the young of the species, with longer periods between molts as the crab matures. During ecdysis (when the crab molts), the old shell breaks and detaches, and the animal is helpless. Many functions, such as reproduction, behavior, and metabolic processes are directly affected by the physiology of the molt.

FROM THE BURSTING OF THE FIRST SKELETON



1 Once the crab reaches adulthood, its exoskeleton covers its body without any change for about 300 days.

2 Between 30 and 40 days before ecdysis, new bristles form, and the epidermis detaches itself.

3 Hours before the break, the lobster takes in large quantities of water until it fills up and breaks the old exoskeleton.

4 During ecdysis itself, the lobster remains immobile for approximately 12 hours, while it grows in size because of hydration.

VULNERABLE
While it waits for the new exoskeleton to grow, the lobster hides so it does not end up a victim of its predators.

In a Stranger's Home

Hermit crabs belong to the Paguridae and Coenobitidae families. Unlike other crustaceans, a hermit crab does not have a hard exoskeleton on its abdomen to protect it. This is why it uses shells from sea snails as protection for part of its body.

Sharp Front Legs

Crustaceans have appendages that generally branch in two directions and are adapted to aquatic life. A characteristic shared by all crustaceans is their articulated shell, which leaves two pairs of antennae uncovered. They also have a pair of mandibles, two pairs of maxillae, and a pair of appendages in each segment of the body. Their pincers have enough strength so they can trap their prey and feed themselves. The class Malacostraca includes lobsters, crabs, shrimp, and prawns, among other animals.

Shrimp

is the name for about 2,000 species of crustaceans of the suborder Natantia. Shrimp are characterized by their semitransparent and flat bodies, with appendages modified for swimming, and by their long antennae. Their length varies between 0.1 inch and about 8 inches (from a few mm to 20 cm), depending on the species. They live in salt water, brackish water, and fresh water. They survive by burying themselves for almost the entire day and coming out at dusk to catch their food.

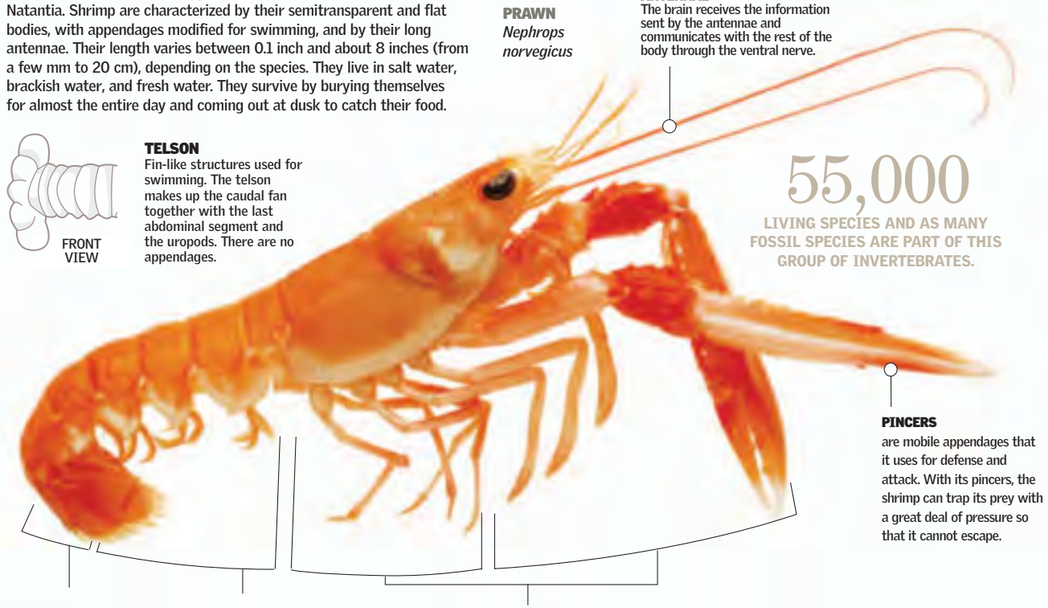
DUBLIN BAY PRAWN
Nephrops norvegicus

ANTENNAE
The brain receives the information sent by the antennae and communicates with the rest of the body through the ventral nerve.

FRONT VIEW

TELSON
Fin-like structures used for swimming. The telson makes up the caudal fan together with the last abdominal segment and the uropods. There are no appendages.

55,000
LIVING SPECIES AND AS MANY FOSSIL SPECIES ARE PART OF THIS GROUP OF INVERTEBRATES.



PINCERS
are mobile appendages that it uses for defense and attack. With its pincers, the shrimp can trap its prey with a great deal of pressure so that it cannot escape.

UROPODS
are shaped like a spade. The telson is like a barb. Both are used by the shrimp for its characteristic escape backwards.

PLEOPODS
First five pairs of abdominal appendages

FIRST TWO PAIRS
have been adapted for sexual functions.

LAST THREE PAIRS
are similar to each other and are used to swim.

PEREIOPODS
Five pairs of appendages

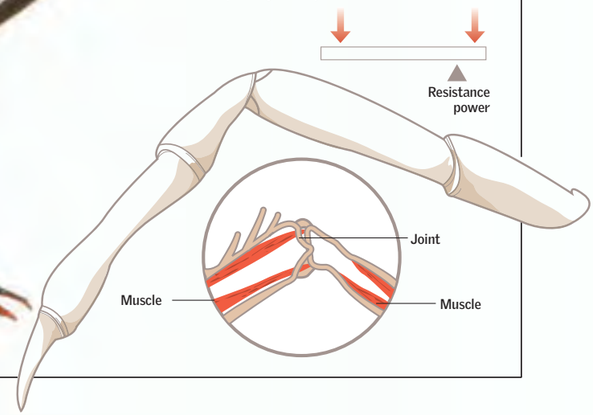
FIRST THREE PAIRS
are used to feed itself. The pincers catch and hold prey.

LAST TWO PAIRS
work as walking legs that are aided by the pleopods.

Lobster

A lobster is characterized by two enormous pincers formed by the first pair of legs. It lives on rocky bottoms in shallow water, and it migrates seasonally toward the coast in summer and to greater depths in winter. The lobster is typically a nocturnal animal seeking its food when the Sun sets. Its food consists mainly of mollusks, bivalves, worms, and fish.

JOINTS AND LEVERS
Crustaceans, with slim limbs and little space for large muscles, are able to move with great strength because the majority of their joints function as simple levers, with the lever arm corresponding to the limb itself, and the fulcrum corresponding to the joint.

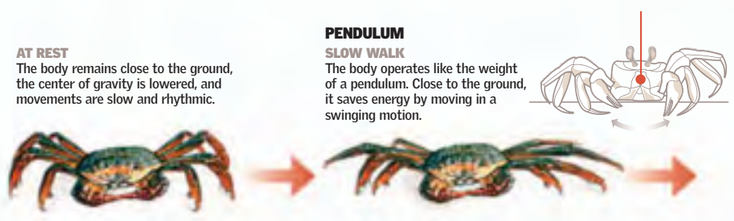


Crab

Of all crustaceans, the crab has surprising mobility and agility. It has five pairs of legs, four of which are walking legs, despite the fact that it moves laterally instead of forward. The crab-like movement is due to the placement of its legs and the general design of its body. A crab's walk is funny, but its technique is effective for both swimming and walking, even over such varied surfaces as beach sand, rock, and –for some species– tree branches.

AT REST
The body remains close to the ground, the center of gravity is lowered, and movements are slow and rhythmic.

PENDULUM
SLOW WALK
The body operates like the weight of a pendulum. Close to the ground, it saves energy by moving in a swinging motion.



REBOUND EFFECT
FAST WALK
Suspended from its joints, the body jumps by means of them and on them and multiplies the energy of its movement.

The body, elevated higher than its joints, tends to fall like an inverted pendulum, which helps with movement.

In the Middle of the Chain

Zooplankton include thousands of distinct species belonging to very different groups. Among these species are protists, coelenterates, worms, crustaceans, and other small, weakly swimming organisms. Unicellular, eukaryotic protists constitute a large group of species of zooplankton. They constitute an extensive and varied community in the food network. The phytoplankton, which are capable of photosynthesis, provide food for the zooplankton. Phytoplankton also serve as food for echinoderms, crustaceans, and larval-stage fish. Once they grow up, the larvae serve as food for schools of small fish, which are in turn food for larger fish, including plankton-feeding whales that sometimes eat these small fish.

Malacostraca

Are typically oceanic, though some have adapted to fresh water, and others are even adapted to life on land. All have a body divided into a 13-segment cephalothorax with 13 pairs of appendages, a stomach with six segments, and, at the extreme posterior, an unsegmented telson.

KRILL
Euphausia superba

Is one of the most abundant and successful species on the Earth. Krill can live five to 10 years, experiencing 10 moltings before reaching their maximum length. Krill typically emit a greenish light that can be seen at night.

REAL SIZE
1.5 inches (3.8 cm)

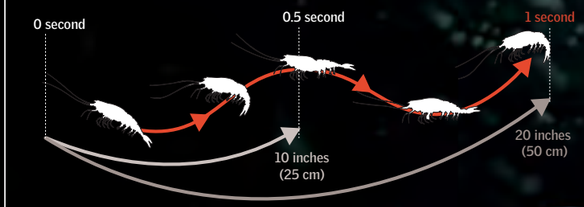
EYE
Krill have only one large, compound, black eye.

LEGS
With their feathery legs krill filter out the small algae on which they feed.

6,600 feet (2,000 m)
DEPTH TO WHICH SWARMS OF KRILL MAY GATHER

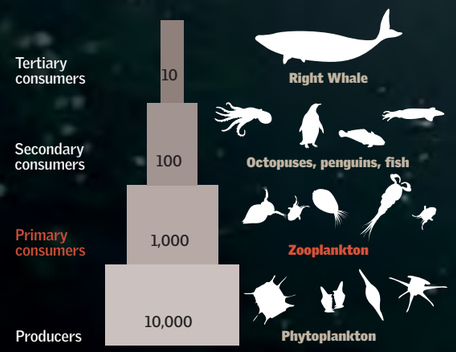
HOW IT FLEES

The krill makes use of its telson, comprising five paddles, to drive itself through the water. It reaches great speed and moves jumping forward and backward. These crustaceans group in giant schools, with thousands of individuals concentrated in each cubic yard of water.



TROPHIC CHAIN

The food cycle is initiated with a vegetable producer, which begins the chain for consumers. Those that feed on producers are primary consumers, those that feed on primary consumers are secondary consumers, and so on.



LUMINESCENCE

Each specimen of krill has a photophore in its abdomen, a structure that allows it to emit light because of a chemical reaction that involves oxygen and various other chemical compounds called luciferin, luciferase, and adenosine triphosphate (ATP). One order of crustaceans is generically known as krill.

12,000
SPECIES OF COPEPODS

Copepods

are aquatic microcrustaceans, though terrestrial ones also exist. They are found in fresh water as well as in salt water. They feed on phytoplankton and are an important component of plankton, which at the same time serves as food for numerous marine animals.

LARGE APPENDAGES
They form very fine combs that filter the water for food.

REAL SIZE
—
0.08 inch (2 mm)

CYCLOPOID COPEPOD
Megacyclops viridis

Cyclopoid copepod larvae are luminescent. After their developmental stage they begin to swim freely. The cyclopoid copepod lives in fresh water. It is among the most numerous invertebrate species found in Europe.

NAUPLIUS LARVA
Cyclops sp.

This little crustacean swims by jumping with its legs. It feeds on animal and plant remains.

FEET
attract the water current toward the larva's mouth, which little particles can enter.

Brachiopods

have a body of variable segmentation, usually a bivalve shell, supplied with leaflike appendages for locomotive and brachial functions (hence the name brachiopod). They are abundant in lakes and still water, feeding on debris and microscopic plants. Because there are few males, eggs from a female can develop without fertilization in new individuals, a process known as parthenogenesis.

WATER FLEA
Daphnia sp.

has two pairs of antennae and feet adapted to swimming and grasping. The second antenna pair serves as a locomotive organ. The water flea feeds on microscopic seaweed and the remains of dead animals.

REAL SIZE
—
0.1 inch (3 mm)

6 to 8 weeks
IS THE AVERAGE LIFESPAN OF A WATER FLEA.

A Special Family

Arachnids make up the largest and most important class of chelicerata. Among them are spiders, scorpions, fleas, ticks, and mites. Arachnids were the first arthropods to colonize terrestrial environments. The fossil remains of scorpions are found beginning in the Silurian Period, and they show that these animals have not undergone major changes in their morphology and behavior. The most well-known arachnids are the scorpions and spiders.

GIANT HOUSEHOLD SPIDER
Tegenaria duellica

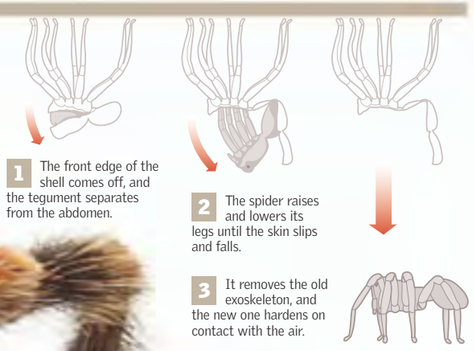
This spider is distinguished by its long legs in relation to its body.

100,000

IS THE NUMBER OF SPECIES OF ARACHNIDS THOUGHT TO EXIST IN THE WORLD.

EXOSKELETON

Growth happens through molting, a process by which the spider gets rid of its old exoskeleton. In its youth the spider grows through successive moltings (up to four a year), and once it reaches adulthood, it goes through a yearly change.



1 The front edge of the shell comes off, and the tegument separates from the abdomen.

2 The spider raises and lowers its legs until the skin slips and falls.

3 It removes the old exoskeleton, and the new one hardens on contact with the air.

The female can transport up to 30 offspring on its back.

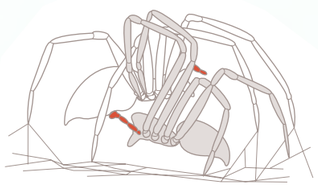
The claws hold the prey and immobilize it.

Scorpions

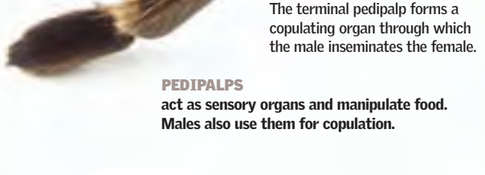
Feared by people for ages, the scorpion is characterized by the fact that its chelicerae (mouth parts that in scorpions are large) and pedipalps form a pincer. The body is covered with a chitinous exoskeleton that includes the cephalothorax and abdomen.

EMPEROR SCORPION
Pandinus imperator

Like other scorpions, it has a stinger crisscrossed by venomous glands. It measures between 5 and 7 inches (12 and 18 cm) long, though some have reached a length of 8 inches (20 cm).

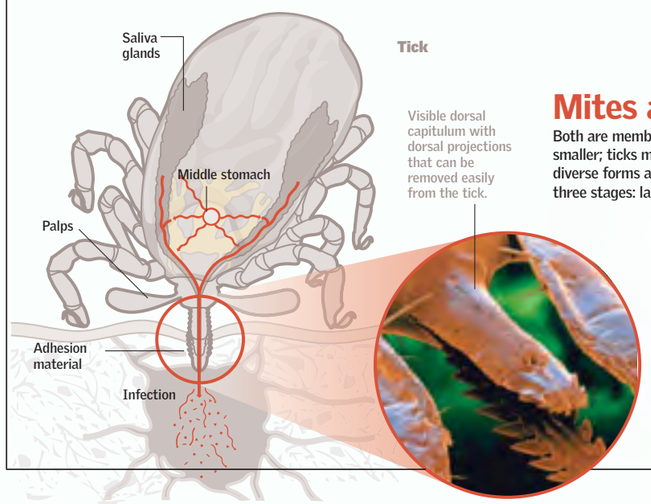


CHELICERAE
move up and down. In the more primitive spiders (such as tarantulas), the chelicerae move side to side like a pincer.



Spiders

are the most common arthropods. They have the surprising property of secreting a substance that, on contact with the air, creates very fine threads that spiders skillfully manage for diverse purposes. Once a female spider mates, she deposits her eggs inside a cocoon of special silk, called an egg sack. The appearance of spiders is unmistakable: the two main sections of the body, the thorax (also called a prosoma) and the abdomen (also called an opisthosoma), are united by a narrow stalk (the pedicel). Spiders have four pairs of eyes, whose distinctive size and placement help characterize different families of spiders. Their chelicerae end in fangs that carry conduits from venom glands. Spiders kill their prey by using their chelicerae to apply venom.



Mites and Ticks

Both are members of the Acari order. They are differentiated by their size. Mites are smaller; ticks may measure up to an inch in length (several centimeters). Mites have many diverse forms and are parasites of animals and plants. Ticks have a common life cycle of three stages: larva, nymph, and adult, during which they live off the blood of their hosts.

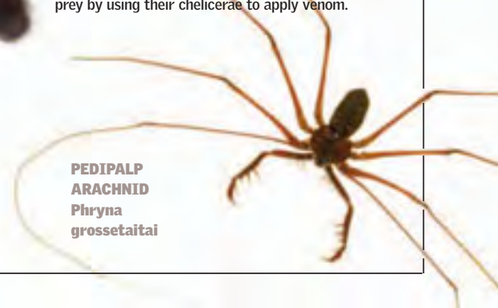
WITH ITS LEGS SPREAD OUT, A SPIDER CAN MEASURE

12 inches (30 cm)

IN LENGTH.

Amblypygi

Small arachnids measure between 0.2 and 2 inches (0.4 and 4.5 cm). The chelicerae are not as large, though the pedipalps are strong and are used to capture prey. The first pair of legs are modified touch-and-sensing appendages, whereas the last three take care of movement. Because of a spider's flattened body, its walk is similar to that of the crab.



PEDIPALP ARACHNID
Phryna grossetaitai

Quality Silk

Spiders are known for the production of silk, with which they construct spiderwebs. With the threads made in their glands, spiders can capture prey, defend themselves, or care for their offspring. Seven types of silk-secreting glands are known, but no spider has all seven types at one time. Inside the gland, the silk that spiders produce is liquid, though it emerges as a solid fiber.

Threads of Silk

The silk thread made by spiders is produced in two or three pairs of spinnerets that contain hundreds of microscopic tubes that lead to the abdominal silk-producing glands. The thread emerges as a liquid that hardens upon being secreted by the spinnerets. These masters of weaving produce many threads at once. When secreting the silk substance, a scleroprotein, spiders cover it with a thin, fatty layer. Scientists believe that some spiderwebs imitate the ultraviolet images of flowers. Such imitation lures many butterflies and bees to fall into the spider's sticky trap.

COMPOSITION
The silk is made of complex proteins. Males as well as females generally have five to seven different types of special silk glands for producing these proteins.

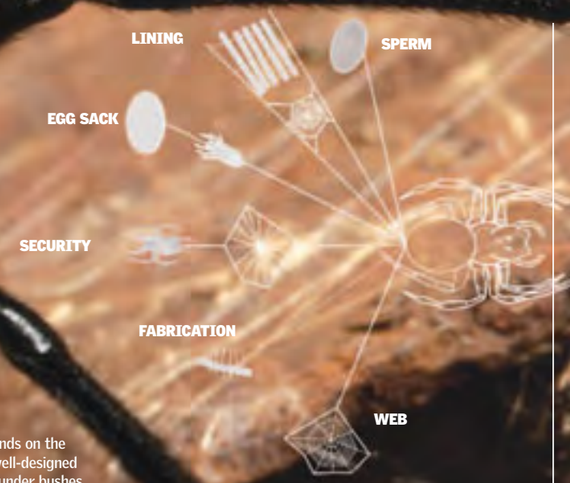
SPINNERETS
The silk emerges through spinnerets; the thin threads are joined to each other before they dry to form a thicker strand.

SILK GLAND
Moves the silk to the spinnerets. The secretion is a liquid substance that is insoluble in water.

30% The amount that a thread of silk can stretch from its original length

Diverse Uses of Thread

In addition to spiderwebs and traps, and shelter lining, spider silk has other uses. The spider can use it as a thread for tracking its position or as a safety thread when it either lowers itself or is suddenly dislodged and falling. A spider can also use the silk thread to suspend itself in midair. Male spiders use silk as a web where they deposit their sperm before leaving in search of a female, who uses the silk to build egg sacks, where she will deposit her eggs.



Architecture

The appearance of a spiderweb depends on the spider that wove it. There are very well-designed structures, such as the hammock web built under bushes by the tiny *Linyphia triangularis*. Other webs, such as those of the families Linyphiidae and Agelenidae, are not made of sticky silk but only a dry variety. The silk of the spider is almost as strong as steel, and it has double the elasticity of nylon. Some giant tropical spiders build spiderwebs that are as strong as fishing nets, with which they can trap even birds.

1 BEGINNING
The threads set up a bridge. The spider lets itself sway in the wind until it falls and finds its footing.

2 TRIANGLES
The spider adds a loose thread fastened to each side of the bridge, moves to the middle of the bridge, and lowers itself to form a triangle with the silk..

3 SUPPORT
The spider creates the support structure that it will attach to a nearby object. This object might be a tree trunk, a wall, or a rock.

4 RADIUS
With the silk glands (glandulae ampullaceae), the spider constructs the spokes of the web. Dry strands that run from one spoke to the next form a spiral.

5 REPLACEMENT
Dry web material breaks from the action of the chelicerae and from food trapped in the web. The spider replaces this broken material with stickier and thicker silk.

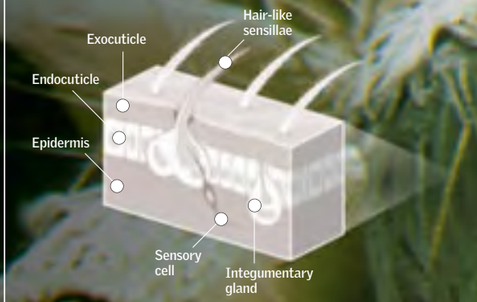
2,500
THE NUMBER OF RECORDED SPECIES OF WEB-SPINNING SPIDERS

Sixth Sense

Spiders do not have good vision and can see only a short distance. For this reason, they carry out many of their activities at night. However, some spiders do have sharp vision. To be aware of the world around them, spiders use the sensory hairs that are located at the ends of their limbs. Each body hair is sensitive to differences in pressure. Some hairs are also capable of transmitting vibrations to the exoskeleton.

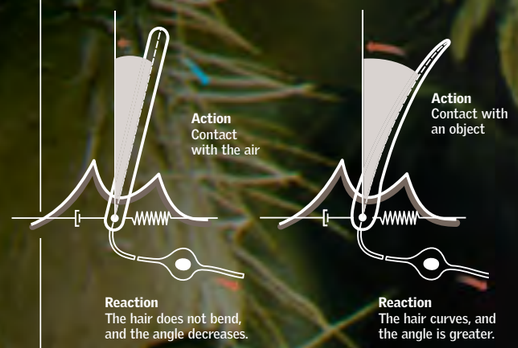
Hairs

Are used to conduct stimuli to the cells. Some are short and stiff, others long and flexible. According to the form of the hair, the mechanoreceptors provide the spider with information about the world that surrounds it. The stimuli induce the animal to flee from enemies, obtain food, and establish the reflexes needed to walk, run, fight, or mate.



TRICHOBOTHRIA
is a long, tactile hair.

TACTILE HAIR
perceives the sensory flow of the environment.



Sensillae

Hairs that feel vibrations and sense the presence of strangers

Trichobothria
perceives movements.

EYELET
Allows for 360-degree vision.

EYE
The retina inside the eye can move in three dimensions, which permits the spider to look in all directions and focus on an object.

PEDIPALP
Appendage used to get to know the environment

CHELICERAE
Appendage with a fang that secretes venom

Chelicerae and Eyes

Chelicerae are formed by two segments: a basal segment that contains the venom gland and the rest of the appendage that forms a fang at the end of which the venom channel opens. Normally spiders have eight simple eyes, each one supplied with a single lens, optical rods, and a retina. The eyes are basically used for the perception of moving objects, but some can form images.

OGREFACED SPIDER
***Dinopis* sp.**
Two powerful eyes

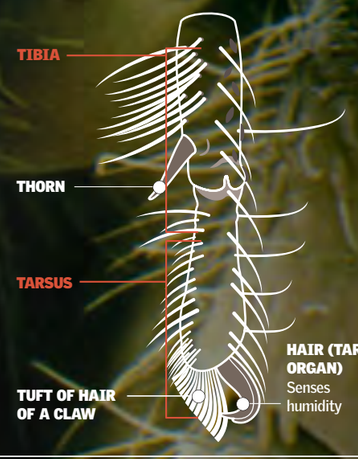
DYSDERA CROCOTA
Dysdera
Six small eyes

JUMPING SPIDER
Phidippus audax
Four large eyes on the front of its head and four smaller eyes on the upper part of the head.

CRAB SPIDER
Xysticus cristatus
Eight spread-out eyes

Pedipalps: Various Functions

The pedipalps consist of six segments and have pincers; they are tactile along almost all of their length, and in the males the ends are modified to form a receptacle that transfers the sperm during copulation. The lower parts of the pedipalps are used for chewing.



Poisonous Sting

Venomous arachnids are the group of arthropods most feared by people. Even if a bite may be fatal to another animal, it is unlikely that it will be fatal to a human being, who would be attacked only as a means of defense in cases of fear or danger. The scorpion stands out among the most dangerous species. It uses its stinger when it wants to be certain of catching a difficult prey. Another notable example is the black widow, whose tiny body produces one third as much venom as a rattlesnake.

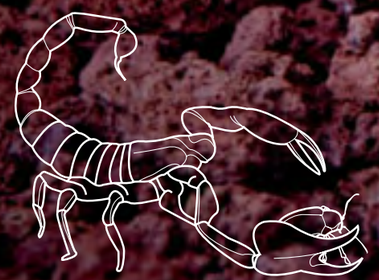
The Most Dangerous

Of the 38,000 known species of spiders, only about 30 have venom that is harmful to humans. Some are hunters or trappers, but others are small, peaceful weavers. The black widow (*Latrodectus mactans*) is one of the shyest. The venom that it injects (toxalbumin) is a neurotoxin that acts principally on the nerve endings. Still, the black widow bites only when provoked. The wandering spider (*Phoneutria fera*) is one of the most aggressive arachnids. It is large, and its venom is fast-acting, capable of killing most prey in 15 minutes.

30 species
of spiders have truly dangerous venom.

1 DETECTS THE PREY
The scorpion does not go out in search of food; rather, it waits until food passes by it. The scorpion can also find food by accident.

2 CLOSES IN
The scorpion directs the front of its body toward the animal, approaching to a distance of 2 to 4 inches (5 to 10 cm), when it lowers its pedipalps in preparation for attack.



3 ATTACK
Once the scorpion is close to its prey, it walks around the victim, trapping it. Then it uses its pedipalps to contain the attacked animal.

4 USE OF THE STINGER
If the prey resists, the scorpion uses its stinger to inject the venom. Venom is administered by the scorpion until it kills the animal.

COMPOSITION OF VENOM

Spider venom is a cocktail of substances, particularly potassium salts, digestive enzymes, and polypeptides. The potassium alters the electrical balance in the nerves and paralyzes the victim. The peptides disable the cardiac muscles and can also attack the nervous system or cause pulmonary edema.

HOW THE STINGER WORKS

Two conduits run from the venom glands to openings at the end of the telson. When the scorpion stings, muscles press the walls of the telson against the venom glands to force venom through the hole of the stinger into a wound. This process is controlled by the scorpion, which administers the proper dose of venom, since it cannot quickly regenerate the venom if it fails.

DESERT SCORPION
Hadrurus arizonensis

SCORPIONS

Scorpions are grouped in six families, the most important being the Buthidae because it contains the most dangerous species for the potency of their venom. The flat form of their bodies helps them hide under rocks, tree bark, and various kinds of debris. Scorpions have nocturnal habits. Cannibalism is common among scorpions, especially after copulation. The only places in the world where there are no scorpions are Antarctica and Greenland.

Conduct of Capture and Sting

Scorpions have long, fine hairs called trichobothria, located in the pedipalps. These perceive the vibration and movement of the wind and help the scorpion detect flying prey and predators. These organs help the scorpion get out of harm's way when danger threatens.

Insects

A PECULIAR SENSE OF SIGHT
This tropical insect has a pair of eyes on each side of its body, giving it a very wide field of vision.

THE SECRET OF SUCCESS 54-55
THE BETTER TO SEE YOU WITH 56-57
TYPES OF MOUTHS 58-59
SUCKING AND PIERCING 60-61
GREAT WALKERS 62-63
HIGH-QUALITY JUMPERS 64-65
THE ART OF FLYING 66-67
DIVING, SWIMMING, AND SKATING 68-69
METAMORPHOSIS 70-73
ORDER AND PROGRESS 74-75
GOAL: SURVIVAL 76-77
ONE FOR YOU, ONE FOR ME . . . 78-79

Insects make up the largest and most varied group of arthropods. Most reproduce easily, and there are insects adapted to any environment. Their bodies are protected by a form of armor. Arthropods are currently believed to be the only living things capable of surviving a nuclear winter. They have highly developed sensory organs that enable them to see long distances. The diversity and sheer number of insect species, estimated at 1.5 million, are a testimony to their evolutionary success. They have been successful, in part, because they are small, need less food than larger organisms, and have extraordinarily developed means of movement that keep them from being easy victims for predators. ●

The Secret of Success

Sensory antennae, appendages on the head that can be used to chew, crush, or grab, highly developed eyes on the sides of the head, and pairs of jointed legs with functions that depend on the species—all are outstanding common features of insects and millipedes (subphylum Myriapoda). Insects, also called hexapods, have six legs attached to the thorax. Myriapods are multi-segmented arthropods that have developed only on land. ●

BILATERAL SYMMETRY
The entire body of insects and myriapods is composed of pairs, arranged along an imaginary axis that passes from the head to the lower end of the abdomen.

Two Pairs of Wings

Some ancient species had three pairs of wings. Today, however, insects have one or two pairs. Butterflies, dragonflies, bees, and wasps use two pairs to fly, but other insects fly with only one pair.

OPEN CIRCULATION
A tubular heart pumps the hemolymph (blood) forward through the dorsal aorta. Accessory contracting organs help push the blood into the wings and legs.

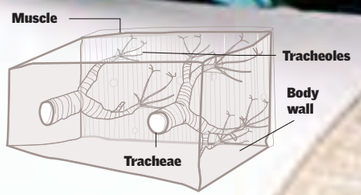
APPENDAGE
contains the genital organs.

SEGMENTED REGIONS
Insects' bodies are divided into three parts: the head (6 segments), the thorax (3 segments), and the abdomen (up to 11 segments).

SPIRACLES
Small entrances to the tracheae

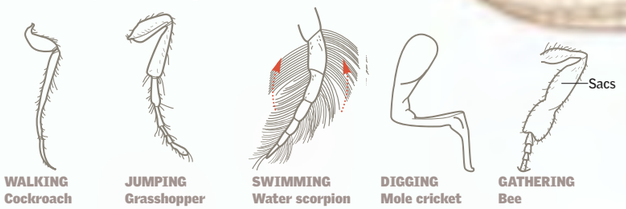
1 million
KNOWN INSECT SPECIES

RESPIRATORY SYSTEM
Land-dwelling arthropods breathe with tracheae. Through branching tubes (tracheoles), air containing oxygen is brought directly to each cell, and carbon dioxide is eliminated.



Legs Adapted for Each Type of Use

The shape of the arthropod legs shown here is closely related to their use and to the arthropod's habitat. Some species have taste and touch receptors on their legs.



STRUCTURE
gives the wings great stability.

HIND WINGS

AT REST
Dragonflies can place their wings against their bodies.

HUNTING
The front legs enclose the prey.

HAWKER DRAGONFLY
Aeshna cyanea

LEGS

THORAX

ANTENNAE

EYES

CLAW

FEMUR

TARSAL SEGMENT

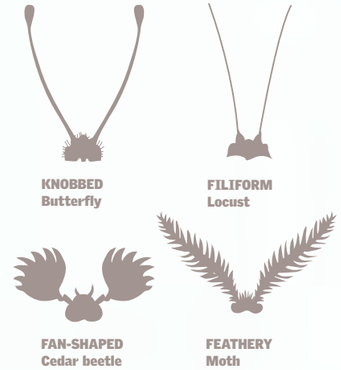
TIBIA

Taking Many Steps

The class Chilopoda (centipedes, including many carnivores and predators) and the class Diplopoda (millipedes) are known as myriapods. Their patterns of movement are both complex and efficient.

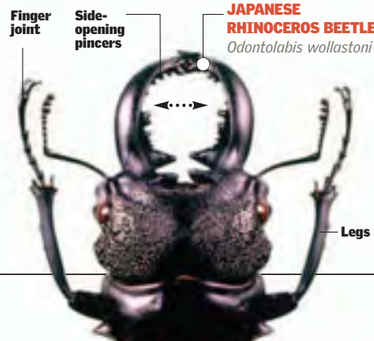
Sensing and Communicating

Antennae are sensory organs. They enable the insect to communicate, and they contain cells shaped like threads or plates. Antennae are adapted in many ways that enable insects to feel, perceive sounds, sense the temperature and humidity, and taste food.



Jaws

The mouth apparatus of insects can be adapted for chewing, licking, sucking, or biting, depending on the species. Beetles (order Coleoptera) have pincer jaws with sensory organs.



The Better to See You With

Just as people without color vision have a hard time understanding what color is, it is impossible for humans to imagine what it is like to see through the compound eye of an insect. These eyes are made of thousands of tiny rods called ommatidia, each one a small eye connected directly to the brain. Scientists theorize that the insect's brain composes the images received from each ommatidium, enabling it to perceive movement in any possible direction-in some species, even from behind.

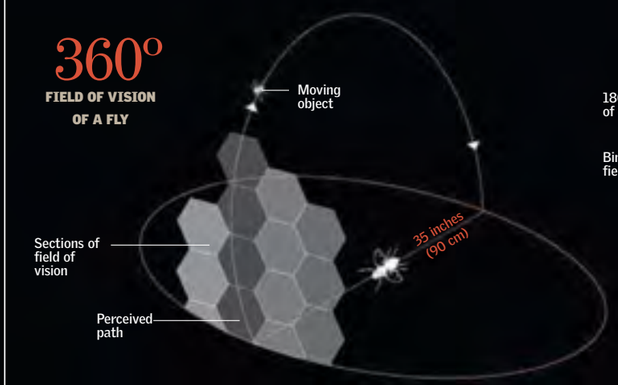
Field of Vision

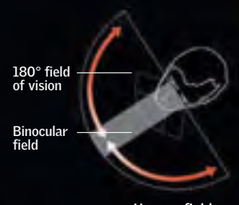
A fly's ommatidia are arranged in circles, and each one covers a portion of the field of vision. Such systems may not yield a high-resolution image, but they are highly sensitive to movement. The slightest motion causes a transfer of sensitivity from one ommatidium to another. This is what makes it so hard to catch a fly.

FLY
Drosophila sp.

ANTENNA

360°
FIELD OF VISION OF A FLY





Human field of vision

A Bee's Eye View

Compared with human vision, a bee's vision is somewhat nearsighted. Even the images of nearby objects are blurry. Its compound eyes have some 6,900 ommatidia.

HUMANS
With binocular vision, a flat and undistorted image

BEES
In a larger field, the same image is narrower.

HEADED FOR NECTAR
Sensitivity to ultraviolet light, invisible to the human eye, enables worker bees to find the nectar inside the flowers.

MOUTH
The mouth has apparatus for licking and sucking.

ANTENNA

One Eye, or Thousands

Each ommatidium is responsible for a small portion of the visual field. Depending on the type of light they receive, the pigmented cells around each rhabdom can vary their diameter, regulating the overall sensitivity of the compound eye.

COMPOUND EYE

OMMATIDIUM

THE HOUSEFLY HAS
4,000
OMMATIDIA.

RHABDOM
Connects each lens with its nerve

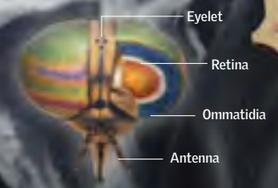
LENS
Cone-shaped, to direct light to the rhabdom

RETINAL CELL

PIGMENT CELL

CORNEA
Hexagonal in shape to fit into the rest of the compound eye

FLY VISION



TYPES OF EYES

PROTECTIVE
The eyelets of the tachinid fly cover its eyes.

VISION IN THE ROUND
Certain dragonflies have a completely spherical field of vision.

CALCULATORS
This common blue damselfly uses its eyes to calculate distances.

Types of Mouths

Far from being a mere opening, the mouth is usually one of the most complex parts of an insect's body. The simple oral appendages of the most primitive forms were gradually modified so that this zoological group has been able to expand its diet. Thus, a hunter's mouth is totally different from that of a sucking insect or a leaf-eater, such as the locust.

LOCUST
Family Acrididae
Since ancient times, locusts have been feared as a great plague on crops.

1 day
THE TIME IT TAKES A LOCUST TO EAT ITS OWN WEIGHT IN FOOD

ANTENNA

COMPOUND EYE

LEFT LOWER JAW

FRONT LEG

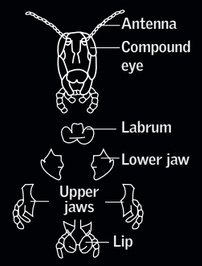
LABRUM

PALP (ON LIP)

Made to order

The oral appendages of primitive insects were modified considerably, and they took different forms according to the species. The first pair of upper jaws is for holding and sucking the food into the mouth. The second pair of upper jaws fuses at the midline during its development to form the lip, a structure with different functions, depending on the diet. The lower jaws and the first pair of upper jaws are at the side of the mouth, and an upper lip, the labrum, protects the front of the mouth. These parts form the basic biting-chewing apparatus. In more advanced forms, its modifications give rise to structures for sucking and licking or for biting and sucking.

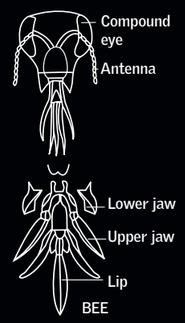
BITING AND CHEWING



LOCUST

Strong lower jaws and dexterous upper jaws

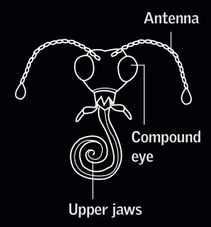
PIERCING AND CHEWING



BEE

Lip for nectar; lower jaws to chew pollen and mold wax

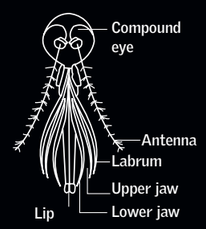
SUCKING



BUTTERFLY

With a small labrum and no lower jaw. The upper jaws form a suction tube.

PUNCTURING AND SUCKING



MOSQUITO (FEMALE)

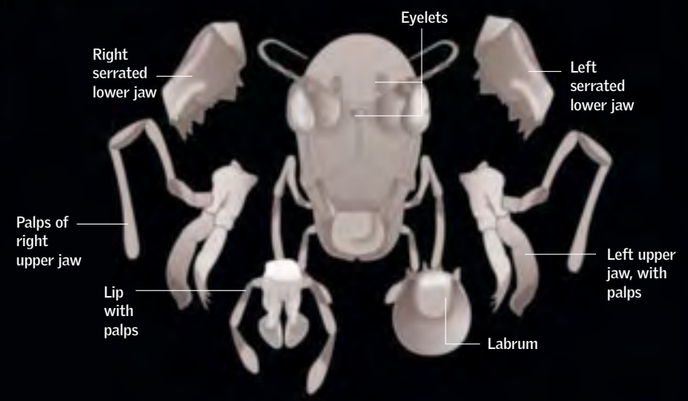
The lip and upper jaws form a tube; the lower jaws are for puncturing the skin, and the labrum forms a sheath.

SEVEN-SPOT LADYBUG
Coccinella septempunctata
feeds on aphids, plant lice, and sand flies.

Leaf Eaters

Insects such as locusts and some beetles, as well as caterpillars (and the larvae of many other species) need a mouth structure capable of cutting leaves into small pieces and then putting them into the mouth. For this purpose their large lower jaws have a series of serrated teeth, whereas the upper jaws and the lip have palps for manipulating and grasping the leaf pieces.

CARNIVORES use their jaws as pincers to grasp their prey.



Sucking and Piercing

Starting with lower jaws adapted for chewing, many insects have developed a more sophisticated oral apparatus, which has enabled them to expand their diet. Mosquitoes, for example, can pierce mammals' skin and feed on their blood using one of the most complex mouths in nature. Flies can eat solid food by using their oral apparatus to begin digestion outside their bodies. Other species have mouths that enable them only to drink liquids. ●

Shapes

PIERCING SUCKING

The Butterfly

Its upper jaws are modified into a retractable tube. It feeds on accessible fluids, such as nectar.

When not in use, the tube is rolled up.

To eat, the insect unfurls the tube.

Upper jaw
Tube for nectar
Interlocking bristles

DETAIL
CROSS SECTION

The Fly

feeds on soft, damp substances. It uses its mouth to put enzymes onto certain solids to soften them so it can sip them up.

Head of the fly
Eyes

1 WETTING
The fly dampens and softens the food with saliva and digestive juices.

2 MAKING SOUP
These digestive juices break the food down and turn it into a partially digested soup.

3 EATING
Once the food is liquefied, the fly sips it up with its proboscis.

Epipharynx
Tube for saliva
Tube for food
Lip
Hypopharynx

STYLETS
Flexible tool used to pierce and hold in place

LIP
Contains one tube for sucking and another for discharging enzymes

MOSQUITO (FEMALE)
Aedes aegypti
This species transmits yellow fever and dengue. Only the females bite, in order to obtain the proteins they need during the time when they are laying eggs.

ANTENNAE
The mosquito's thread-like sensory organs. To bite, it brushes them against the skin of its victim.

UPPER JAW PALPS

COMPOUND EYE

0.001-0.01 ml

AMOUNT OF BLOOD SUCKED BY A MOSQUITO IN ONE BITE

How the Mosquito Bites

1 PERFORATION
With its stylets, the mosquito perforates the skin to hold itself in place and inserts the labellum (lower end of the proboscis) through the skin.

2 ABSORPTION
After injecting saliva to prevent clotting, the mosquito sips the blood of its victim.

Labrum
Lip
Upper jaw

DETAIL
CROSS SECTION

Head
Eyes
Antennae
Stylets
Saliva
Blood rises through the tube.
Blood

Great Walkers

Etymologically speaking, myriapod means "many feet." The term refers to two very different classes of invertebrates: Class Chilopoda and Class Diplopoda, better known as centipedes and millipedes. All are animals divided into segments. Centipedes, most of which are carnivores, have a pair of legs on each segment, and millipedes have two pairs of legs per segment. These invertebrates (which are not insects) have so many legs that, to walk, they must use a highly sophisticated timing mechanism that seems to follow mathematical principles.

Applied Math

To walk, land-dwelling arthropods arch their bodies and move their six legs in coordination so that when one leg moves forward in a power stroke, the ones in front, behind, and opposite it are in a recovery phase, remaining on the ground. Myriapods have a similar mechanism, although it is much more complex because of their large number of legs. The legs are jointed, but they do not function independently of each other for the arthropod to move forward. The segmented body moves side to side in a regular wave pattern, and the legs are functionally adapted to this body movement.

SINUOUS PATH

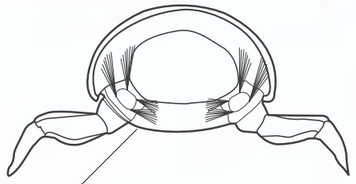
Not only does an arthropod's body move in wave patterns; when the legs on one side of its body are closest together, those on the other side are farthest apart. This alternating pattern is repeated all along its body.

A CENTIPEDE'S LIFE

Female centipedes lay eggs in the spring and summer. These invertebrates can live up to six years, and it takes them three years to reach maturity.

A Thousand Legs

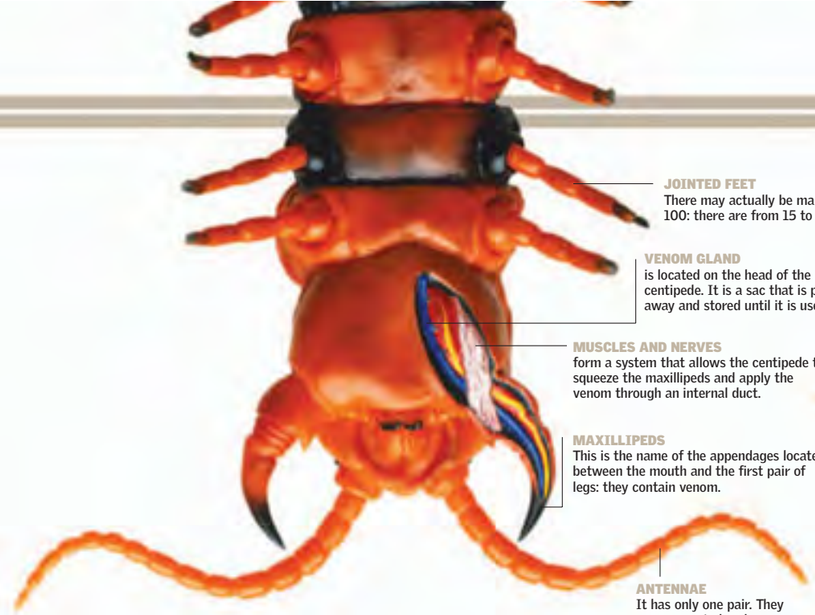
Millipede, or diplopod, is the name of land-dwelling invertebrate species with multi-segmented bodies that have two pairs of legs on each segment. They live in damp places and feed on decomposing material. All of them have a pair of simple eyes and a pair of antennae, lower jaws, and upper jaws. The largest do not exceed 4 inches (10 cm) in length.



1 **LIKE CLAWS**
The back legs of this centipede, almost perpendicular to the rest, are used to trap and hold prey while it injects its catch with venom by means of powerful jaws.

SIZE OR QUANTITY

There are species of centipedes that add segments throughout their lives; others are born with a fixed number of segments that grow in size.



Scolopendrida

SCOLOPENDRA CINGULATA (MEGARIAN BANDED CENTIPEDE)

Typical size	4 inches (10 cm)
Maximum size	12 inches (30 cm)
Quantity of segments	20-40

2 **DEADLY WEAPON**
Holding the prey with the back legs, the centipede doubles itself over, the tips of the maxillipeds (forceps) fasten like claws, and the venom is discharged through the opening at the tip.

Chilopoda

These centipedes use venom to paralyze potential prey, generally small invertebrates. It is produced in a gland near the head and is applied through the maxillipeds. When the adjoining nerve connections give the order to contract the muscle of the maxillipeds, the mechanism is put into motion, and the venom flows through the internal duct. With few exceptions, it is not a venom harmful to people, although the bite is painful and produces localized pain.

Centipedes

They are long and flat and covered by a layer of chitin. They have one pair of legs for each section that forms the trunk. Centipedes live on land and are almost all carnivores; many are venomous. The head of the chilopod has one pair of eyes in the back, consisting of two groups of eyelets, a pair of antennae, a pair of lower jaws, and one or two pairs of upper jaws. Almost all seek dark places, avoiding the light. These invertebrates can measure between 0.15 inch (4 mm) and 12 inches (30 cm) long.

1 **SMALL BULLIES**
An Australian centipede, like the one in the picture, can make a person sick for a week with its bite, and it is capable of killing a dog. It measures 5 inches (12.5 cm).

2 **CRUSHERS**
Geophilomorpha have a very long body, are yellow in color, and have 25 pairs of legs; the last diverge from the axis of the body. Their strategy is to attach themselves to a worm or earthworm until they crush it.

Predators
All centipedes are carnivorous and venomous. The largest tropical centipedes can eat worms, insects, and even small birds and mammals.

Quality Jump

Fleas are well known for their extraordinary jumps. When they are adults, these small, wingless insects take advantage of their jumping ability to hunt for their food, the blood of birds and mammals. They are ectoparasites of dogs, cats, and chickens, which keeps them present in our daily lives. They invariably bite their hosts and suck the blood that circulates through their skin.

Superprotein

The capacity to jump is related to the presence of resilin, a protein of great elasticity similar to rubber. Flea resilin has the function of building tension in the jumping legs. The release of accumulated energy generates the jump. On occasion the jump is useless, and the flea does not manage to place itself on the host. Far from being a failure, the fall adds to the tension of the resilin, which makes the rebound a longer jump.

FLEAS IN THE HOME
Fleas are very common on dogs and cats. Fleabites generate serious discomfort for domestic animals because scratching irritates and injures their skin.

1 Preparation

Within tenths of a second, the flea prepares itself to jump. It compresses the resilin and at the same time contracts its back legs. The back legs have a system of pads that retain the tension and accumulate energy.

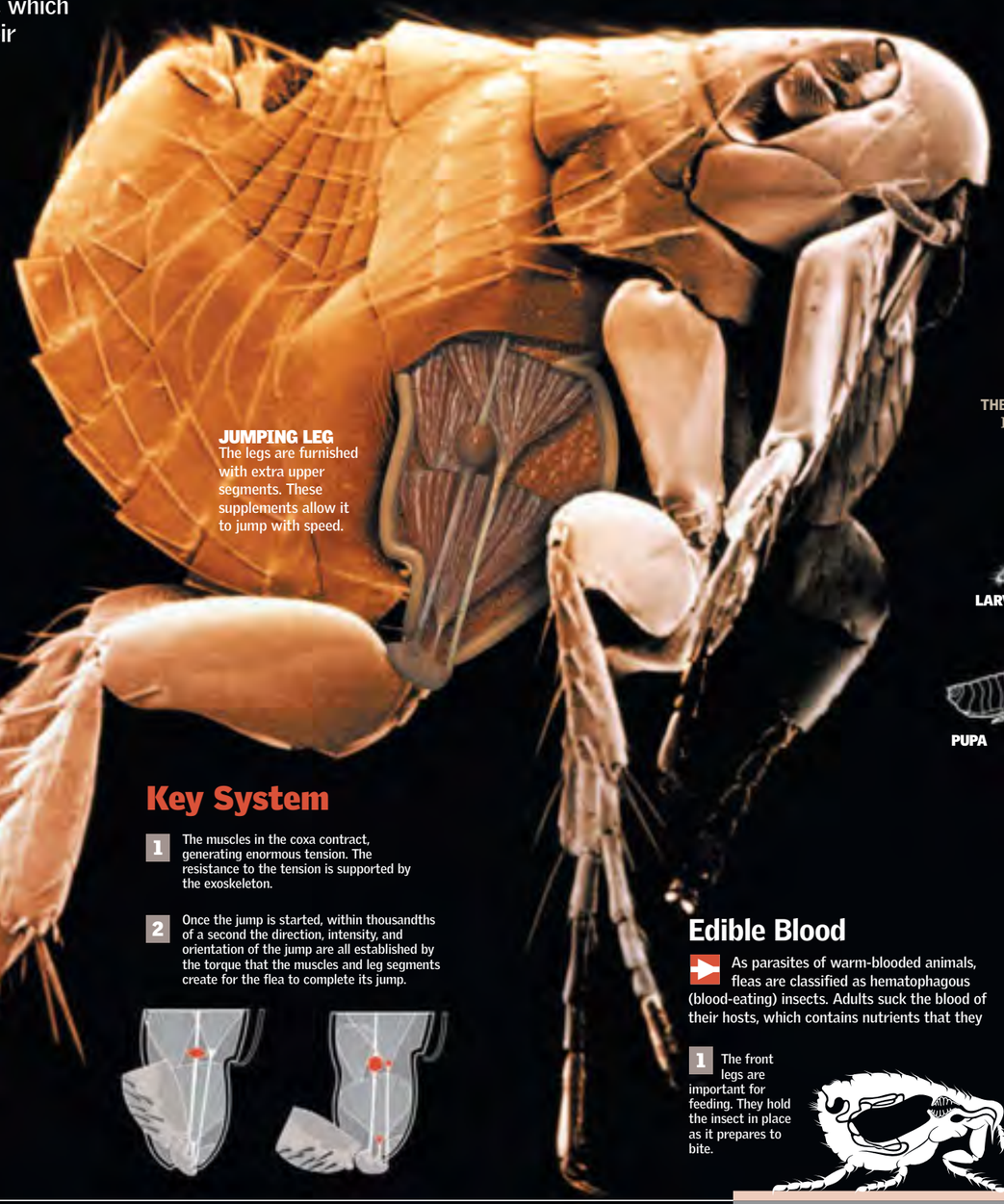
2 Action

The flea accumulates energy by tensing the muscles of the thorax and legs. When the accumulated elastic energy reaches a certain level, the flea releases its legs. As a result the legs generate a sudden movement that causes the flea to jump.

FLEAS CAN SURVIVE

3 months

WITHOUT EATING.



JUMPING LEG
The legs are furnished with extra upper segments. These supplements allow it to jump with speed.

Key System

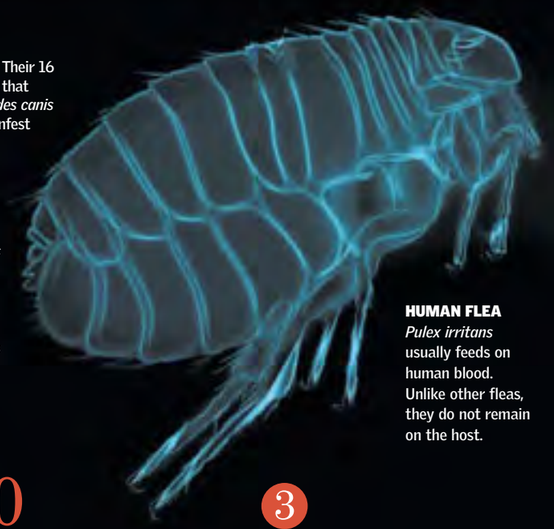
1. The muscles in the coxa contract, generating enormous tension. The resistance to the tension is supported by the exoskeleton.

2. Once the jump is started, within thousandths of a second the direction, intensity, and orientation of the jump are all established by the torque that the muscles and leg segments create for the flea to complete its jump.

Order of Jumpers

Fleas are in the class Insecta, order Siphonoptera, which includes wingless insects that are external parasites and lack wings. Their mouth apparatus is for piercing and sucking, and their life cycle is one of complete metamorphosis. Their 16 families include the genera of fleas that infest cats and dogs (*Ctenocephalides canis and C. felis*), as well as those that infest hens (*Ceratophyllus gallinae*).

DOG FLEAS
Ctenocephalides canis
This species is responsible for 90 percent of flea infestations in dogs.



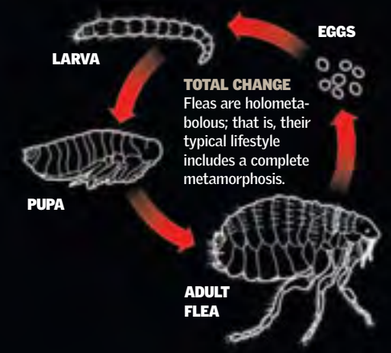
HUMAN FLEA
Pulex irritans usually feeds on human blood. Unlike other fleas, they do not remain on the host.

200 times

THE DISTANCE A FLEA CAN JUMP IN TERMS OF BODY LENGTH

3 In Flight

A flea can leap 24 inches (60 cm) at one bound. Its body is protected by armor-like overlapping plates that make up its exoskeleton. During a series of jumps, fleas can fall on their backs or heads without being injured.



TOTAL CHANGE
Fleas are holometabolous; that is, their typical lifestyle includes a complete metamorphosis.

Life Cycle

A complete cycle, from egg to adult, can take from two to eight months. The length of the cycle varies by species and by temperature, humidity in the environment, and the availability of food. In general, after feeding on blood, the female lays 20 eggs per day and up to 600 eggs throughout her life. The eggs are laid on the host (dogs, cats, rabbits, mice, rats, opossums, humans, etc.).

Edible Blood

As parasites of warm-blooded animals, fleas are classified as hematophagous (blood-eating) insects. Adults suck the blood of their hosts, which contains nutrients that they use for their own nutrition. Females use these nutrients to produce their eggs. The dried blood ejected in the adults' feces is also useful as food for various types of larvae.

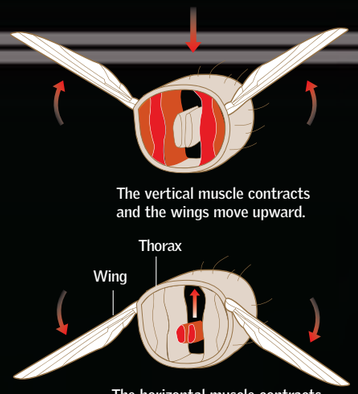
1. The front legs are important for feeding. They hold the insect in place as it prepares to bite.

2. On injecting their stylet, fleas expel a substance that irritates the host but helps the fleas by keeping the blood from clotting while they are sucking it.

FLEA VS. MAN
A flea jumps a distance equivalent to 200 times the length of its body. To equal this feat, a man would have to jump over a 130-story building.

The Art of Flying

One of the most basic adaptations of insects has been their ability to fly. Most have two pairs of wings. Beetles (order Coleoptera) use one pair to fly and one pair for protection. For example, the rounded body of a ladybug or ladybird is nothing more than the covering for a very sophisticated flight system. It makes these small beetles, which are harmless to humans, great hunters in the insect world.



The vertical muscle contracts and the wings move upward.

The horizontal muscle contracts and the wings move downward.

"Ladies" of Land and Air

Some 4,500 species of these beetles live throughout the world. Almost all are brightly colored, with black spots on a red, yellow, or orange background. These colors warn away predators, who usually associate bright colors with poison. In fact, some ladybugs are actually poisonous for small predators, such as lizards and small birds. Ladybugs pose the greatest danger to agricultural pests such as plant lice and gadflies, so they are often used as a natural biological pest control.

1 Preparation

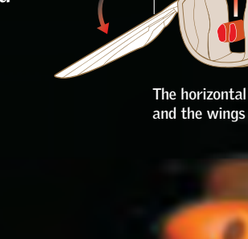
The elytra can separate from the rest of the body. They protect the thorax, and also the wings when folded inside.

ELYTRON
Name of the modified front wing of beetles

2 Takeoff

Although the colorful elytra are not used in flying, the insect needs to lift them in order to unfold its wings, which are seen only during flight.

FRONT VIEW OF ELYTRA



BACK VIEW

3 Flight

With the elytra open and spread like airplane wings, the second pair of wings is free to move. The muscles at their base control the direction of flight.

40-80 inches per second
(1-2 m/s)
AVERAGE SPEED OF FLIGHT

SEVEN-SPOTTED LADYBUG
Coccinella septempunctata
Thanks to their help in destroying pests, during the Middle Ages these beetles were considered instruments of divine intervention from the Virgin Mary.

The insect is between 0.04 and 0.4 inch (0.1-1 cm) long.

APOSEMATISM
The opposite of mimetism: these insects use their bright colors to scare away danger.

4 Landing

The insect reduces its flight speed. With its wings outstretched, it settles down to touch the surface without gliding. Its hind legs help it to stay balanced.

BODY ARMOR
The elytra are brought close to the body. Then the wings are folded underneath.

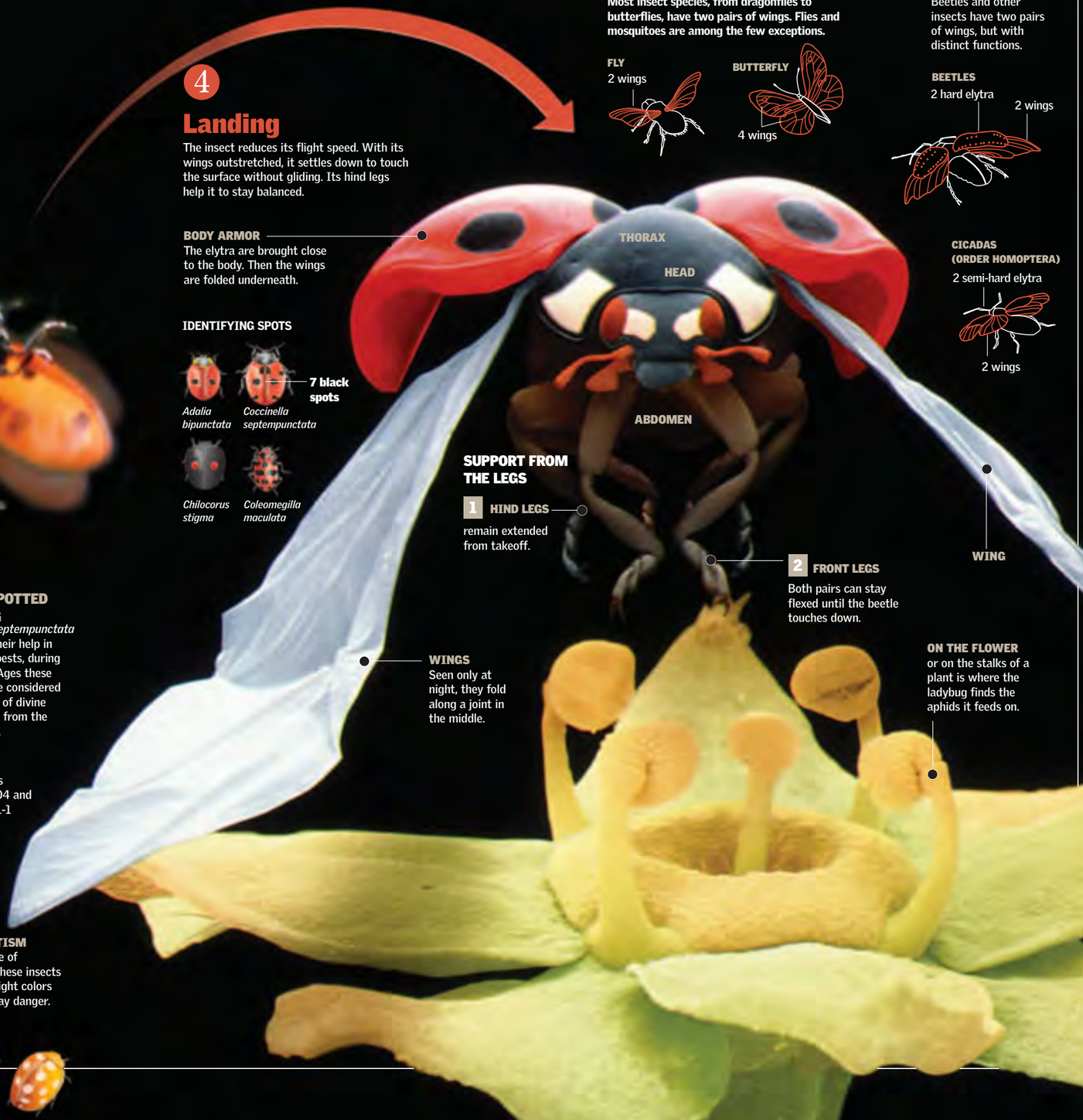
IDENTIFYING SPOTS

Adalia bipunctata — *Coccinella septempunctata*

Chilocorus stigma — *Coleomegilla maculata*

A QUESTION OF NUMBER
Most insect species, from dragonflies to butterflies, have two pairs of wings. Flies and mosquitoes are among the few exceptions.

OTHER FUNCTIONS
Beetles and other insects have two pairs of wings, but with distinct functions.



SUPPORT FROM THE LEGS

1 HIND LEGS
remain extended from takeoff.

2 FRONT LEGS
Both pairs can stay flexed until the beetle touches down.

WINGS
Seen only at night, they fold along a joint in the middle.

ON THE FLOWER
or on the stalks of a plant is where the ladybug finds the aphids it feeds on.

Diving, Swimming, and Skating

For some insects, such as pond skaters in freshwater, or halobates in saltwater, the biblical feat of walking on water is no miracle, but an everyday task. When the waters are calm, the water insect known as a pond skater uses the surface tension of liquid (and certain anatomical features of its body) to do honor to another one of its names: "water strider." But because they need air to breathe, any movement on the surface sends them skittering back to land. Other species have gone further and become divers and swimmers, with mechanisms for breathing and moving underwater.

Underwater

There are several aquatic beetle species, with two basic adaptations: the hind legs, in pushing the beetle forward, work like oars, presenting a greater surface area when moving backward than forward, and the elytra can trap air as a reserve for breathing underwater. These species are among the major predators in stagnant freshwater environments. The diving beetle measures about 1.4 inches (3.5 cm) long.

It rises to the surface to fill the air chamber.

AIR

DIVING BEETLE
Dytiscus marginalis

On the Water

Until recently, it was believed that insects of the family Gerridae skated on lagoons and ponds using a type of wax secreted by their legs. Later it was discovered that their feet have large numbers of micro-hairs, 30 times finer than a human hair, that trap tiny air bubbles. The trapped air forms a cushion that keeps their feet from getting wet, and if the feet begin to sink they are buoyed to the surface.

WATER STRIDER
Neogerris hesione
This species lives on freshwater surfaces. It measures 0.5 inch (1.3 cm) long.

HIND LEGS
provide force to slide along the surface.

Insects of the order Heteroptera have divided wings (hemielytra), with one half that is hard and the other membranous.

ABDOMEN

MIDDLE LEGS
Used as skates to glide along the water

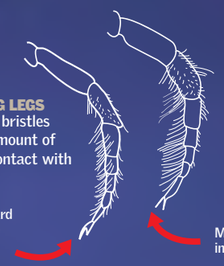
THORAX

CABEZA

ANTENNA

FRONT LEGS
are shorter than other pairs. They are used for trapping prey.

SWIMMING LEGS
A system of bristles varies the amount of surface in contact with the water.



Moving forward decreases the surface area.

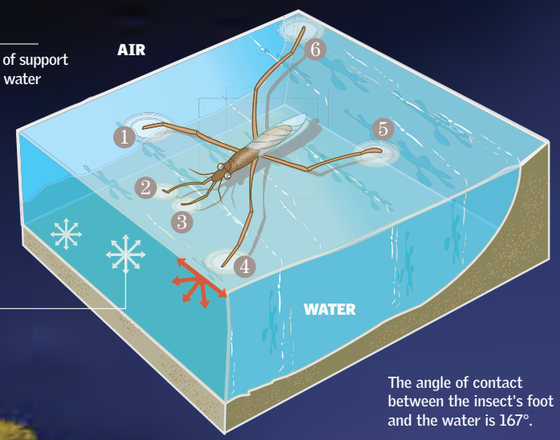
Moving backward increases the area.

SHORT FRONT LEG

WALKING ON WATER
The legs are arranged on the surface of the liquid in such a way as to make it an elastic film. The hind legs use this property for support and traction. Also, the insect supports itself on segments of its legs, not on just one point.

LEGEND
x Points of support on the water

AIR



SURFACE TENSION
The mutual pressure among molecules of liquid brings the molecules together so that they resist pressure that would penetrate the surface.

Each molecule exerts pressure in all directions.

The angle of contact between the insect's foot and the water is 167°.

The middle and hind legs grow from separate points on the body.

5 feet per second
(1.5 m/s)
AVERAGE SWIMMING SPEED

THE SURFACE TENSION CAN WITHSTAND
15
times the insect's total weight.

The middle pair of legs is longer.

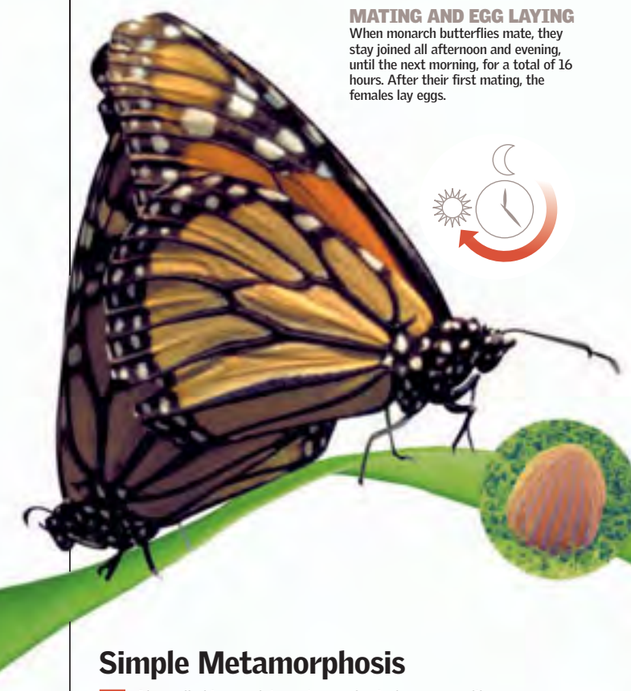
Metamorphosis

Metamorphosis is the change in shape that insects undergo as they grow. There are two types of transformations: complete, like that of monarch butterflies, and incomplete, like that of dragonflies or grasshoppers. Insects with complete metamorphosis pass through an immobile state (called the pupal, or chrysalid, phase) in which their body is transformed by hormones within a cocoon.

1 In the Beginning, the Egg

The adult female lays eggs among the leaves, where they will be protected. Monarch butterfly eggs have colors ranging from grayish-white to cream, and they are shaped like barrels, 0.1 inch (2 mm) in diameter. The larvae grow inside the egg until they hatch; after hatching, they eat the shell.

MATING AND EGG LAYING
When monarch butterflies mate, they stay joined all afternoon and evening, until the next morning, for a total of 16 hours. After their first mating, the females lay eggs.



7 days
AMOUNT OF TIME THE LARVA LIVES INSIDE THE EGG

FIVE CHANGES
When it hatches, the insect is shaped like a worm. This caterpillar will molt its exoskeleton five times as it grows in size. Its internal structure will not change, however. Each new exoskeleton is larger than the one before.

Hatching from the egg
The exoskeleton hardens. As the insect grows, the exoskeleton becomes too small. Eventually it splits and falls off.

Second shedding

Third shedding

Fourth shedding

Change to pupal phase

2 Larva or caterpillar

makes its entry into the world by eating its shell. From then on, eating and growing will be its main activities. Every time it sheds its skin, the old exoskeleton is broken. The insect forms a new, soft exoskeleton, which is gradually expanded by blood pressure. The exoskeleton then undergoes a chemical reaction that hardens it.

3 weeks
IS THE AMOUNT OF TIME THE INSECT LIVES IN THE LARVAL STAGE.

A SIMPLE ASSIGNMENT
In the caterpillar phase, the insect focuses solely on eating leaves. In this way it accumulates the necessary energy for the physiological processes of metamorphosis. For digesting the leaves, the caterpillar has a very simple digestive track.

PREPARATION FOR THE PUPAL PHASE
Before passing to the next stage, the larva stops eating and eliminates any food left in its digestive tract. The juvenile hormone, which keeps the transformation of the body in check, starts to become inhibited.

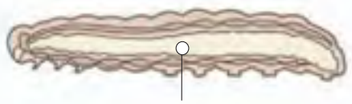
CREMASTER
The caterpillar secretes a fibrous cushion that sticks to the stalk of a plant. It hangs from the cushion with hooks on the end of its abdomen.

EXOSKELETON
Crossed with yellow, black, and white stripes, it is soft after every shedding and later hardens. The insect always emerges head first.

HANGING AND IMMOBILE
To leave the larval stage behind and become a pupa, the caterpillar quietly awaits the transformation.

FAREWELL TO THE OLD BODY
The larva's last exoskeleton begins to fall off and is replaced by a greenish tissue that will form the cocoon, or chrysalis.

INSIDE THE LARVA
The insect's heart, nervous system, and breathing system are almost completely developed during the larval stage, and they change very little afterward. The reproductive system is formed later.



Simple Metamorphosis

Also called incomplete metamorphosis, because, unlike complete metamorphosis, it does not include a pupal phase. The wings and legs develop gradually, so that the insect does not need to spend a certain amount of time immobile. Locusts, cockroaches, termites, and dragonflies have this type of metamorphosis. From an evolutionary standpoint, it corresponds to ancient or primitive insects. One of its characteristics is the nymph stage of young insects. The nymph gradually changes in shape as it grows. When it sheds its exoskeleton, the adult emerges.

EMPEROR DRAGONFLY
Anax imperator

3 Pupa (chrysalis)

After getting rid of its larval exoskeleton, the insect hangs immobile from a branch, protected by a cocoon. Inside, it will develop its distinctive butterfly form. Although it does not eat during this period, it is intensely active biologically and undergoes considerable change. Histolysis, a process in which the larva's structures are transformed into the material that the insect will use to develop adult structures, takes place at this time.

HISTOGENESIS

New tissues are generated from hemolymph (the equivalent of blood), the Malpighian tubules (the energy-producing organ in insects), and histolyzed tissue, including the larva's muscles. The monarch butterfly pupa is called a chrysalis because of the color and structure of the capsule that protects it. It is oval-shaped with gold and black spots.

BUTTERFLY SHAPE

The adult butterfly's wings and legs develop from the cuticle, or skin tissue, which is composed mostly of chitin. Other organs are preserved or rebuilt from regenerative cells.

15 days

LENGTH OF THE PUPA, OR CHRYSALIS, PHASE

HORMONES IN FULL SWING

Metamorphosis is governed by three hormones. One is the cerebral (brain) hormone, which stimulates the prothoracic gland. This gland produces the molting hormone ecdysone, which causes the loss of the old skin. The third hormone is the juvenile hormone, which slows down the transformation to the adult stage.

WITHIN SIGHT

As the time draws near for the adult to emerge, the chrysalis becomes thinner, changes color, and becomes transparent. The transformed insect can be seen inside.

CAMOUFLAGE

The chrysalid capsule has shapes, textures, and colors that help keep it from being noticed, to protect it from predators. The capsules typically resemble leaves or bird droppings.

INTERNAL ORGANS

Inside the chrysalis, the insect's body is changing into that of an adult. The intestine rolls into a spiral shape to assimilate liquid food, and the reproductive organs are developing for the adult stage.

INTESTINE

TRANSFORMATIONS OF THE FLY

This side diagram shows the changes in the organs of a fruit fly (*Drosophila* sp.) from the pupa stage to the adult stage. The cuticle of the last larval stage protects the pupa. This transparent membrane allows the wings, the antennae, and the folded legs to be seen while they are forming. The pupa already has the dimensions of the adult flying insect, and it will not grow any bigger during the rest of its life.

Mouth
Antennae
Eyes
Legs
Wings
Reproductive organs

4 Adult

After reaching its final shape, the butterfly will not grow any more. When the butterfly emerges from its cocoon, its wings are still wrinkled and damp. It will need to hang upside down to stretch them out to dry, so that they will be useful for flying. This will take several hours of waiting and struggling. From then on, the butterfly will feed on nectar.

BREAKING FREE

To permit the butterfly to emerge, the mature capsule splits along its length. The insect gradually stretches its new body and activates the circulation of the hemolymph.

YOUNG ADULT

Once free of its covering, the adult is usually pale in color, and its wings are soft and folded. After about 40 minutes the wings expand, harden, and take on their full color.

ELIMINATING WASTES

While emerging, the butterfly secretes a fluid containing the waste produced during the chrysalis phase. This fluid, called meconium, is considered rather foul-smelling.

JOINED, BUT NOT FOREVER

After leaving the chrysalis, monarch butterflies from the same litter stay together for a period of three to eight days before they go their separate ways.

FLY AWAY, BUTTERFLY

The lifespan of this insect in its adult phase will depend on its luck, its migrations, and the attacks of predators . . .

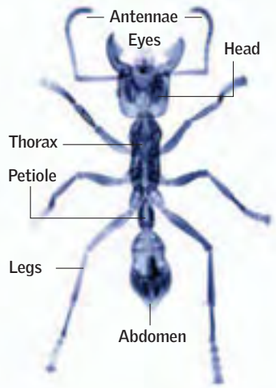
from 5 to 7 weeks

UPS AND DOWNS OF LIFE AS AN ADULT

Mating, reproducing, and laying tiny eggs to give rise to new generations will be the main activities of the adult insect. Each female lays an average of 100-300 eggs during her life.

Order and Progress

Ants are one of the insects with the highest social organization. In the anthill, each inhabitant has a job to do. The head of the family is the queen, the only one that reproduces. All the rest of the ants are her offspring. During mating, queens and drones (males) from various colonies mate on the wing. The queens need to mate several times, because the sperm they receive will have to last their lifetime.



BLACK GARDEN ANT
Lasius niger

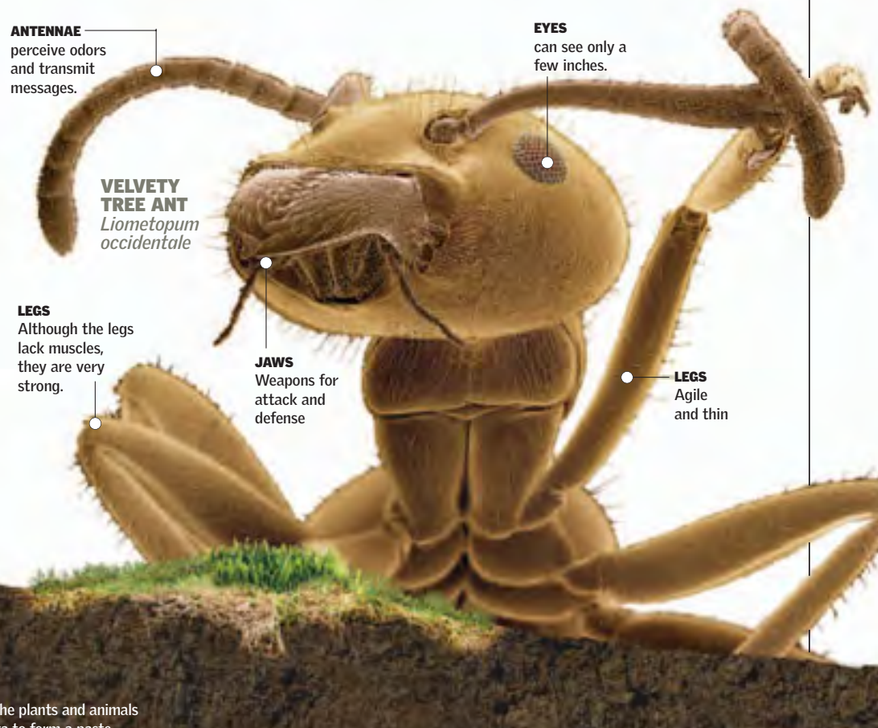
The Castes

Each ant plays a role in the nest and is assigned its role at birth. Drone, soldier, worker, and replete worker (which stores food reserves) are the castes that distinguish what chores each ant will have.

QUEEN
The largest ant. She lays the eggs that will become workers, drones, and new queens.

DRONE
His only function is mating; afterward he dies.

WORKER
The worker ant may have the role of gathering food, cleaning, or protecting the anthill.



The Anthill

After mating, the queen loses her wings and chooses a place to lay eggs. At first she lives on reserves derived from the muscle mass of her wings and some of the first eggs she has laid. She takes charge of raising the first generation of worker ants, which will then take care of finding food while the queen focuses exclusively on laying eggs.

COMMUNICATION
An ant communicates with its antennae through chemical means, by capturing particles of certain substances (pheromones) that enable it to recognize another ant from the same colony. Ants do not have a well-developed sense for perceiving sound.

MAIN ENTRANCE

UNUSED TUNNEL
will be reopened when the anthill gets too hot.

FOOD STORAGE
Honeypot ants coordinate the food supply.

UNUSED TUNNEL

METAMORPHOSIS
In the egg stage, the future ant remains near the queen but leaves her during the larval stage. Other ants then take care of the larva, and it will become a nymph and form a cocoon to cover itself.

THERE ARE ABOUT
10,000
ANT SPECIES.

1 EGGS
are laid by the queen in the lowest area.

2 LARVAE
are carried to another chamber to grow.

3 NYMPHS
are fed and taken care of in another area.

4 COCOONS
The new ants hatch ready to work.

QUEEN ANT

YOUNG ANTS

Feeding

Ants cannot eat solid food. The plants and animals they eat are mixed with saliva to form a paste, which is used to feed the whole colony.

INTERCHANGE OF FOOD
Having two stomachs, an ant can share food. The transfer begins when the receiving ant uses its front legs to touch the lip of the donor ant.

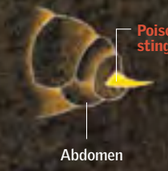
Defense

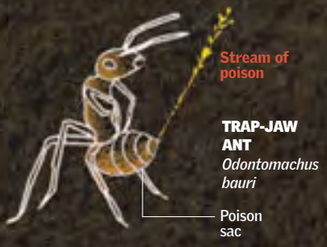
The most widely used defense is biting and spraying streams of formic acid. Soldier ants have the job of scaring away the enemy because they have larger heads than worker ants.

JAW
The jaw is the ant's main weapon of defense, with a bite that can scare away or harm a rival. The jaw is also used for hunting and feeding.

VENOM
may contain formic acid and can kill or paralyze the prey. It comes from special glands in the lower abdomen.

SOUTHERN WOOD ANT
Formica rufa





Goal: Survival

Evolution has molded some striking traits into living beings. In particular, some insects, disguised as branches or leaves, can escape notice so as to hunt or to hide from predators. To avoid being attacked, other insects develop colors and shapes that deceive other animals and keep them from attacking. Hiding and showing off are two opposite strategies that have been favoring the survival of the fittest for millions of years.

PEACOCK BUTTERFLY
Inachis io
The flashy, aposematic (warning) coloration keeps predators away by warning of the danger the insect poses.

FALSE EYE
The scales are pigmented to look like eyes.

Warning Signals

Mimetism is the imitation of characteristics belonging to dangerous or bad-tasting animals. Replicating the colors and shapes of dangerous animals is known as Batesian mimicry. On the other hand, if an insect produces foul-smelling substances to disgust the predator, that is called Mullerian mimicry.

DOUBLE PROTECTION
Caligo sp.
Owl butterflies combine Batesian and Mullerian mimicry. Predators can confuse the owl butterfly with leaves, but if a predator succeeds in finding it, the butterfly folds its wings to look like the shape and eyes of an owl. The predator, confused, backs off from attacking.

BRIMSTONE BUTTERFLY
Gonepteryx sp.
The profile of the wings resembles the shape of cut leaves.

WINGS
These wings look like leaves, with a similar color, shape, and structure.

Defense

The most widely imitated insects are ants, bees, and wasps, because they produce toxic substances that can be deadly.

BODY
Branch-shaped abdomen

LEGS
imitate twigs with dry leaves.

AUSTRALIAN STICK INSECT
Extatosoma sp.
This stick-like insect sways back and forth as if tossed by the wind.

Disguise

These insects use survival strategies designed to keep predators from seeing them. This disguise is their only means of defense.

VEINS
In an extraordinary simulation, the veins look like the veins of leaves.

Masters of Simulation

Camouflage, or crypsis, is a phenomenon in which animals use amazing disguises as advantageous adaptations. Camouflage is used both by hunters and by potential prey. Insects' bodies may be disguised as various substrates and parts of trees, such as bark, leaves, and branches. These masking techniques are a convenient way for the insect to fade into the background.

EYES
Compound; enable them to monitor their environment

FRONT LEGS
move slowly so that the prey will not detect them.

THISTLE MANTIS
Blepharopsis mendica
These mantises use camouflage to hunt unsuspecting insects that get too close to their powerful front legs.

One for You, One for Me ...

The biological relationships between species can have both positive and negative consequences. One relationship that has good results is mutualism, a relationship between species in which the organisms benefit each other. For example, ants and aphids (plant lice) have established a beneficial interaction. Ants defend and nurture the development of aphid colonies on a plant. In return, the aphids provide a sugary substance to feed their protectors.

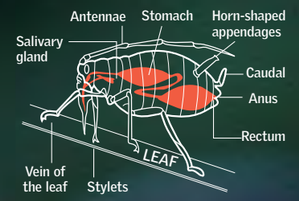
KEPT IN RESERVE

Aphids need protection from predators, such as butterfly larvae. Ants pick up eggs and nymphs in their jaws and carry them into their anthills, out of the reach of any predator.

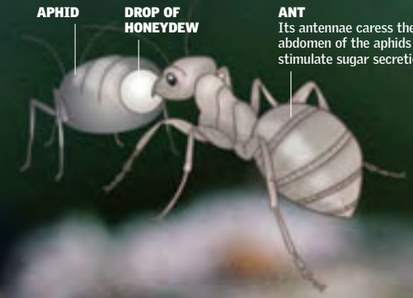
Sugar Currents

Generally, aphids form colonies that live on a single plant. They usually place themselves on the underside of a leaf, where the aphids can reach the leaf's veins. The veins carry sugars from the leaves to the remainder of the plant, and the aphids use this flow of sugar as a source of food.

APHID
Extracts nutrients from the leave's ribs with its stylet



PARTNERS
Sugars are the product that links these insects.



ANT
Its antennae caress the abdomen of the aphids and stimulate sugar secretion.

2,200 pounds (1,000 kg) of honeydew
ARE EXTRACTED FROM A COLONY OF APHIDS BY ANTS EVERY YEAR.

Chain Reaction

The beneficial interaction between aphids and ants can produce secondary effects. In some cases, plants benefit indirectly from the presence of aphid-protecting ants. These guardian insects drive away the herbivores that feed on the tender leaves. In this way, plants invest less energy to replenish their photosynthesizing organs.

BLACK GARDEN ANT
Lasius niger
is between 0.1 and 0.2 inch (3 to 5 mm) long. The thorax is fused to the first abdominal segment.

BLACK BEAN APHID
Aphis fabae
is between 0.05 and 0.1 inch (1.5 to 3 mm) long. It has very short antennae.

HONEYDEW
is a secretion with a high concentration of simple sugars.

Relationship with People

THE HIVE
Movable frames allow the beekeeper to remove a frame with young bees and in this way start a new colony.

THE NEVER-EMPTY HOME 82-83
AFLOAT WITH DUST 84-85
BEEKEEPING 86-87
HUNGRY TOGETHER 88-89
BENEFICIAL VAMPIRES 90-91

Apiculture, or keeping bees to use their products, is a very old practice. Originally, people only hunted beehives. Not only did they eat the honey from the beehives; they also mixed it with water and left it to ferment so they could make alcoholic drinks. Today the production of honey has been perfected in such a way that other products, such as pollen, royal jelly, and propolis, or bee glue, are also obtained from the hive. Just as useful as bees, leeches have always been used as therapeutic tools to soothe headaches and stomach upsets. In this chapter you will also learn what happens when insects such as locusts reproduce at dangerous rates. ●

The Never-Empty Home

The home can be another place colonized by invertebrates. Some arrive seeking humidity, shelter, or food; others are attracted by the scent of skin, wool garments, or wooden ceilings. Generally, they are considered a threat and are fought, but some can be truly beneficial. There are insects, for instance, that can act as a plague control in the garden. Various strategies can help keep some "ecologic balance" in the home. ●

In the Garden

The home garden is a natural environment in which food chains become established. Species such as snails, which feed on plants, can be destructive. But carnivorous species can keep harmful species at bay. Earthworms and some beetles serve as environmental cleaners because of their eating habits.

LADYBUG
Coccinella septempunctata
eats fleas and gnats.

SNAIL
Helix aspersa
is a nightmare for the green leaves in the garden.

PILL BUG
Armadillidium vulgare

BURYING BEETLE
Nicrophorus sp.

SPINY-HEADED WORM
Phylum Acanthocephala

BLACK ANTS
Lasius niger
can go from their nest to the interior of the house.

EARTHWORM
Lumbricus sp.

Plagues and Illness

When the females feed on human blood, mosquitoes (such as those belonging to the family Anopheles, bearers of malaria) and other insects become vectors for illnesses, since they can transfer microscopic parasites to people. For this reason, bodies of stagnant water, which is where mosquito larvae develop, should be avoided.

BLOODSUCKING BUG (TRIATOMINE)
Triatoma infestans
Triatoma **transmits Chagas disease to humans. Chagas disease produces cardiac, digestive, nervous, and respiratory complications. When *Triatoma* bites a human, it excretes waste on the skin that can contain the parasite *Tripanosoma cruzi*. The parasite then enters the bloodstream when the victim scratches the bite. This insect lives mainly in makeshift dwellings, between thatched roofs and unbaked bricks.**

HOUSE DUST MITES
Dermatophagoides farinae
Some dust mites carry parasites; others cause allergic reactions.

MOSQUITO
Aedes aegypti
is the vector for yellow fever and dengue fever.

LARVAE

RUE
Ruta graveolens
Soaked in water this plant repels insects.

THYME
Thymus vulgaris
This herb attracts pollinating bees and repels flies.

FLIES CARRY AT LEAST
65 infectious illnesses.

"Magic" Carpet

Keeping carpets clean within the home is critical, because few are the insect species that live in a carpet and are nice to humans.

FLEAS
Ctenocephalides sp.

COCKROACHES

CENTIPEDES

A COLONY OF 60,000 TERMITES CAN EAT
2 ounces (5 g) OF WOOD PER DAY.

AUGER BEETLES
Xylopsocus sp.
The adult beetle lays eggs, and the larva burrows into wood, creating tunnels 0.25 inch (0.6 cm) wide in the wood.

WASPS
Apis mellifera
build their nests (hives) under the eaves.

TERMITES
Nasutitermes sp.
Live inside the wood they feed on.

In the Roof

The wood in roof beams and spaces between them forms a unique environment within a house, especially for the insect order Hymenoptera. Likewise, several species of beetles feed on wood and lay their eggs in it.

TO CONTROL PLAGUES
Many plants, alone or in combination with other plants, are effective and selective.

LAVENDER
Lavandula angustifolia
repels ants (10 ounces in a quart [300 g in about 1 l] of boiled water).

BLOODSUCKING BUG (TRIATOMINE)

SPIDERS
Their presence indicates that there are many insects in the house.

ORIENTAL COCKROACH
Blatta orientalis

At Night

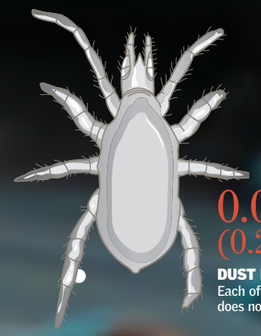
Some "inhabitants" of the house avoid daylight and prefer the cover of darkness so they can go unnoticed by people or predators.

Afloat with Dust

Dust mites are minuscule arachnids that move among dust particles searching for food. The larvae of the smallest species barely reach .004 inch (100 microns). Ticks are larger and can reach .5 inch (1 cm) in length. Their body is full of grooves that absorb humidity, and their life spans fluctuate between three and four months. They adapt to almost any habitat: marine, freshwater, or land.

Small, They are Found Everywhere

Dust mites are part of the oldest, most varied, and largest group of animals that have existed since life appeared on the planet-the arthropods-and, within the arthropods, the arachnids. Their body form is highly varied. Contributing to this variety is the arrangement and appearance of their legs and hairs. They can have a thin, elongated body or a short, wide body; their bodies can also be oval, round, cone-shaped, or rhombus-shaped, and the colors depend on the species. There are green, red, violet, orange, and even transparent mites. These insects are distributed throughout the world, and they have adapted to every environment: they live on the ground, in plants, in storage products, in the water, and in the skin of animals.



0.001 inch
(0.2 mm)

DUST MITE
Each of its legs has six parts. It does not fly; the air carries it.

HAIRS
come out of the mites' legs. These are actually sensory organs.

Humidity

A fact that many people are not aware of is that the presence of mites is closely linked to humidity. These minuscule animals can cause severe harm at home. They can cause many respiratory illnesses, including asthma. Because dust mites need humid conditions in order to live, every room should be well-ventilated.

3 DUST MONSTERS

House dust mites are so tiny that up to 5,000 of the animals can live in just one grain of dust. Their characteristics include a bulky body, eight short legs, and short sensory hairs. They have appendages next to their mouth that they use to tear or bite and, to their side, pincers with which they hold objects. The body is almost monolithic, practically without differentiation among its parts. Even though dust mites do not bite and are themselves harmless, their eggs and feces cause severe symptoms in people who are allergic to them.

CUTICLE
Even though it is solid and flexible, it must be kept humid.

Flying Waste Matter

The microscopic fragments of fecal matter of the dust mite are carried through the air very easily, blending with dust particles. In this way they are transported for great distances, and they are one of the most common causes of allergic reactions.

Liquid Food

When they come in contact with what will be their food, dust mites secrete digestive juices that soften and liquefy solids because their mouth or ingestion system lets them ingest only liquid food.

MOUTHPIECES
In these bugs the mouthpieces are in a small front projection, the capitulum (gnathosoma), formed by the appendages that surround the mouth. On each side there is a chelicera that tears, crushes, or bites the food.

1 SARCOPTES MITE

The *Sarcoptes scabei* is a tiny mite that lives under the corneal layer of the epidermis in passages that the female makes in the skin, where she lays her eggs. Between 10 and 14 days later these eggs become adult sarcoptes mites. The presence of this mite under the skin produces intense itching, which can be severe and which can worsen at night. There are special creams and lotions to treat this infection. If boils appear, the infections must be treated with antibiotics.

2 TICK

The tick is the largest acarid; its body has no divisions, and it feeds on the blood of its hosts. It is generally found among tall grasses or in plant leaves, waiting to hook onto any animal or person that passes by. When a tick succeeds in doing so, it uses a hook-like structure in its mouth to penetrate the skin and to begin to suck blood. Once its body swells with blood, the tick lets go.

0.10-0.25 inch (3-6 mm)

Favorite Places

House dust is a conglomeration of small, suspended particles. The content of household dust varies from home to home, and it depends on, among other things, construction materials used and the presence of domestic animals. A dust particle can contain fibrous material, skin scales, animal hair, bacteria, mold, and other natural or synthetic materials. Mites can live among such particles because they feed off those materials.

Beekeeping

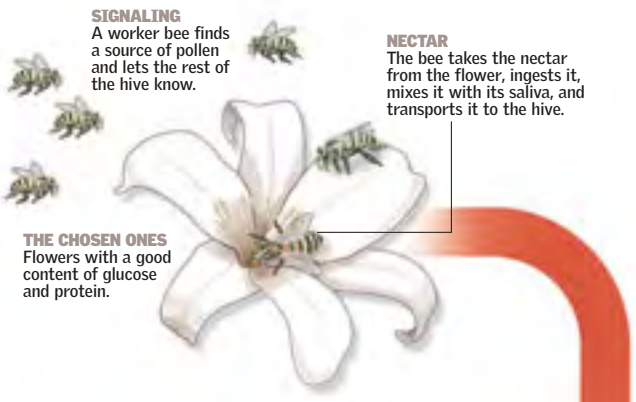
The bee is the only insect that humans have kept from antiquity for their own benefit. Thanks to beekeeping, people have been able to collect the honey that bees produce. Honey was the most widely used sweetener in Europe and Asia until the spread of sugarcane during the Middle Ages. With the introduction of new techniques, modern apiculture also obtains pollen, propolis, and royal jelly from bees. Shown here are some details of the basic components of a beehive.

Nature's Engineering

Honey is one of the substances that the bees themselves eat. The bees make honey out of flower nectar and pollen from the green parts of plants. They carry the pollen to the hive as a source of protein and use propolin, a tree resin, as a form of antibiotic. Apiculture seeks to promote natural production processes in order to make use of these substances for human benefit.

1 The Bee's Work

Worker bees, the real workers of the hive, carry out their duties from the minute they are born: they build and maintain the cells, feed the larvae and the queen, and clean and protect the hive. Outside the hive, they are in charge of collecting flower pollen and nectar.



SIGNALING
A worker bee finds a source of pollen and lets the rest of the hive know.

NECTAR
The bee takes the nectar from the flower, ingests it, mixes it with its saliva, and transports it to the hive.

THE CHOSEN ONES
Flowers with a good content of glucose and protein.

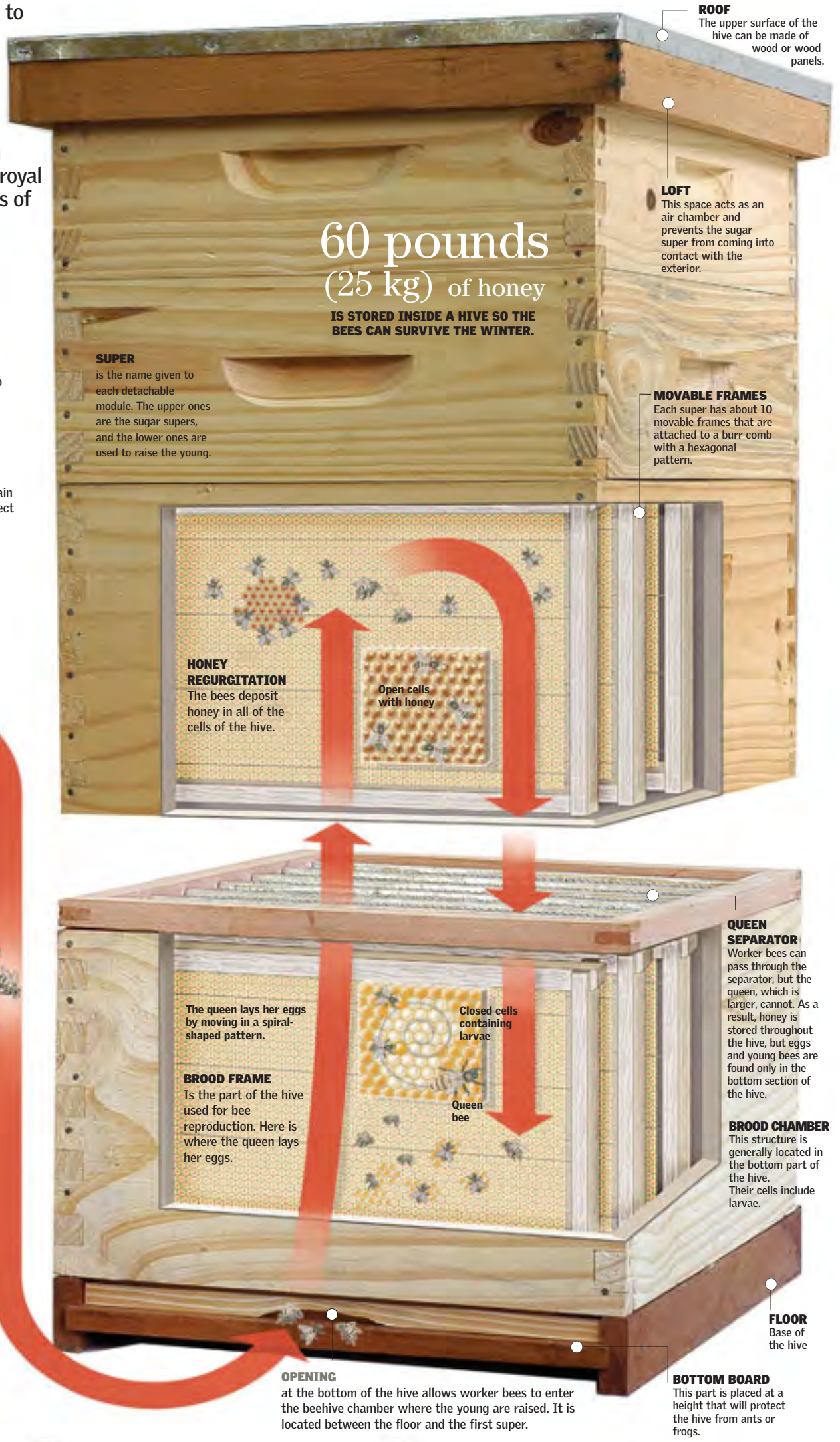
NECTAR, HONEY'S SOURCE
Nectar is made up of 80 percent water and is secreted at the base of the flower's corolla. Honey's flavor depends partly on its aromatic composition, and the beekeeper can select the principal flowers that are the source of the nectar by changing the location of the hive.

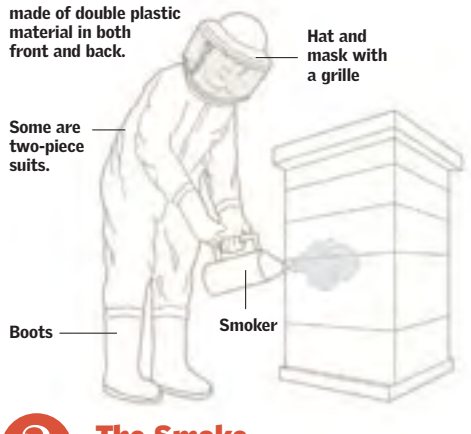
30,000
bees live in a typical hive.
THE POPULATION OF THE HIVE IS KEPT STABLE AS LONG AS NO SUPERS ARE ADDED.

2 Honey Collection

The beekeeper chooses a super, removes it from the hive, and takes out the movable frames by hand. To handle these frames, the beekeeper uses a special suit and other equipment to protect against bee stings. The honey is removed from the detachable frames in a centrifuge, and the frames are then put back into the hive.

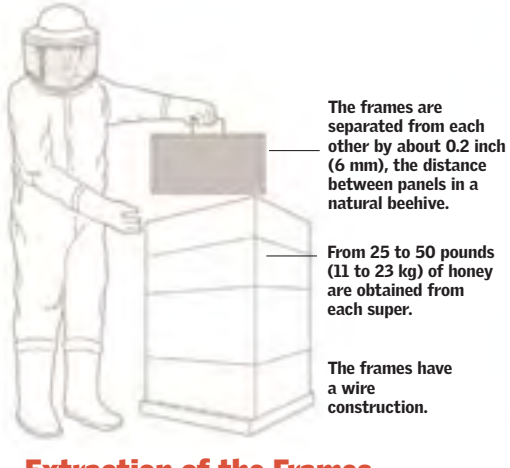
THE ARTIFICIAL HIVE
has movable panels and frames that permit extraction of the hive's products without destroying the bee colony. This system was invented in 1851 by Langstroth, an American.





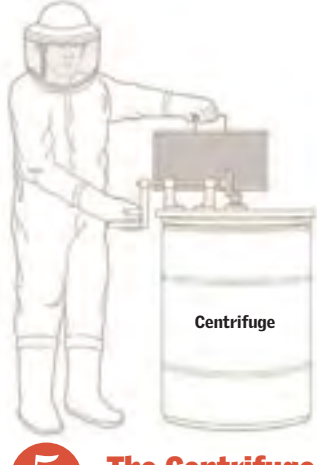
3 The Smoke

Applied by means of a smoke-producing mechanism, it scares the bees and causes them to eat honey, reducing their tendency to fly and sting.



4 Extraction of the Frames

The movable frame system allows for frame removal without affecting the young brood, and the frames can be used again. Before Langstroth's invention, these frames were fixed in place.



5 The Centrifuge

is a machine that rotates. The honey is heated to a temperature that liquefies it. It is drained from the frames and separated from the wax.

Mechanical centrifuges typically rotate at 200 rpm.

6 Filtering and Bottling

The honey is stored in steel tanks for a week and up to a month to allow any impurities to separate. Bottling and storage require an environment that is dry to prevent the honey from absorbing moisture and that is free of any odors, which might contaminate the honey.

Hungry Together

Under specific environmental conditions, locusts reproduce very rapidly and form a swarm. In Africa, the Middle East, and India locust plagues destroy vegetation and produce great crop losses. Consequently, this type of plague represents a great danger to agriculture and causes great economic loss, hunger, and illnesses in affected populations. Chemical, physical, and biological methods are used to repel the locusts, reducing the harmful effects of the invasion.

How Does the Plague Start?

When rainfall creates the appropriate conditions for their reproduction, locusts that live in desert or semiarid regions multiply at a dizzying rate. If the species is in the solitary phase, it is harmless, but when rains come and bring about abundant plant life, the locusts gather together, increasing their reproductive capacity. At that point the locusts mutate into their gregarious phase and change not only their movements but also their morphology. Each female is capable of laying 120 eggs, so that an area of 2.5 acres (1 ha) can breed up to 600 million locusts, which will gather into mile-long swarms that travel large distances in search of food.

SUMMER BREEDING AND CONSECUTIVE MIGRATION ZONE

Locusts reproduce at a rate of millions at a time, and they devour all of the food that lies along their path. The map shows the two main summer breeding zones.

WINTER AND SPRING BREEDING AND CONSECUTIVE MIGRATION ZONE

The swarm of locusts moves to other zones in order to reproduce and feed itself. Afterward, during winter and spring, the locusts retrace their path, and the cycle starts over again.

100 tons

OF VEGETABLES ARE WHAT A MEDIUM SWARM OF LOCUSTS, FORMED BY 50 MILLION INSECTS, EATS IN ONE DAY.

1931

IS THE YEAR WHEN A LOCUST PLAGUE ATE ALL OF THE CROPS AND LEFT CLOSE TO 100,000 PEOPLE DEAD IN NORTH AFRICA.

Locust Plague

The species that causes plagues of locusts on the African continent is the desert locust, *Schistocerca gregaria*. This insect belongs to the Acrididae family and to the order Orthoptera. The locust has an elongated body, about 2 to 3 inches (6-8 cm). The locust modifies its behavior and appearance in response to environmental conditions. It also feeds on most crops, on wild plants, and on some trees, such as sapwoods.

Pest Control

The countries victimized by locusts defend themselves by chemical or biological means on the land or from the air. Pesticide use is restricted, and pesticides can be used against a swarm only when it has begun to form, because misapplication of a pesticide can affect other insects and crops. The locusts are controlled by the application of poisonous bait and by plowing up the ground to bury the eggs.

LOCUSTS IN ANTIQUITY

The devastating effects of locusts can be traced back thousands of years. Locusts were known as one of the seven plagues of Egypt.

Beneficial Vampires

Leeches are worms that have been used as therapeutic tools for thousands of years. History relates that they were used as a remedy for headaches, stomach complaints, eye diseases, mental illness, and other conditions. As the use of drugs increased, the medicinal use of leeches was gradually forgotten. In the 1980s, however, leeches once again began to be used in microsurgery and reconstructive surgery.

THE *DECAMERON*

Illustration of a chapter of the *Decameron* by Boccaccio, which shows the use of leeches to treat illnesses. The patient is the Roman emperor Galerius, who has a disease that causes the putrefaction of the body. The three doctors, aghast at his condition, have put leeches on his body to cure him.

Ancient Uses

The use of leeches in medicine goes back over 3,000 years. In Greece, Rome, and Syria these worms were used to remove blood from many areas of the body. It was believed that bloodletting, or phlebotomy, could cure anything from local pains to inflammation and mental disease. In the 18th and 19th centuries, leeches were sold in European pharmacies, and they became very popular in the therapies of the day, especially in France.

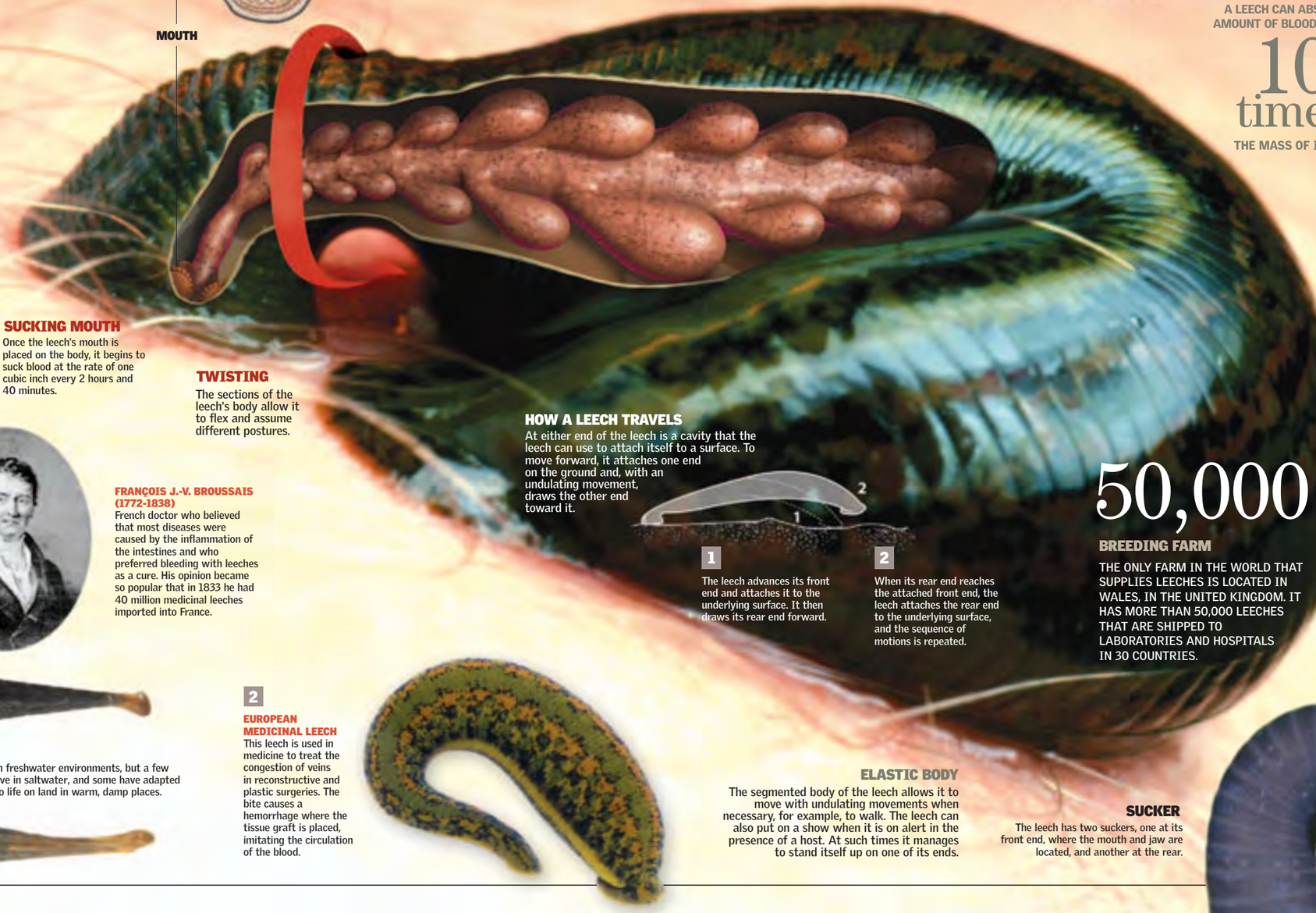
FRANÇOIS J.-V. BROUSSAIS (1772-1838)

French doctor who believed that most diseases were caused by the inflammation of the intestines and who preferred bleeding with leeches as a cure. His opinion became so popular that in 1833 he had 40 million medicinal leeches imported into France.

TEETH

With 300 teeth in its triple jaw, the leech cuts the victim's skin and sucks the blood with its powerful pharynx and the sucker on its mouth. Between the teeth it has glands that secrete hirudin, which keeps the victim's blood from clotting.

MOUTH



SUCKING MOUTH

Once the leech's mouth is placed on the body, it begins to suck blood at the rate of one cubic inch every 2 hours and 40 minutes.

TWISTING

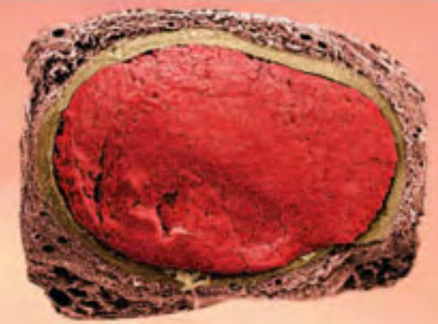
The sections of the leech's body allow it to flex and assume different postures.

Lifesaving Saliva

Every time these worms bite a host, substances are mixed into their saliva from glands in their mouth. Anticlotting components, vasodilators, and anesthetics have been identified among these substances, which are extracted and used in clinical medicine. Researchers are also trying to fabricate synthetic leech saliva through the use of bioengineering techniques.

BLOOD CLOT

While feeding on blood, the leech secretes its own anticlotting agents so that the blood will not spoil inside its body while waiting to be digested. Its salivary glands produce hirudin, a specific thrombin inhibitor.



A LEECH CAN ABSORB AN AMOUNT OF BLOOD EQUAL TO

10 times

THE MASS OF ITS BODY.

HOW A LEECH TRAVELS

At either end of the leech is a cavity that the leech can use to attach itself to a surface. To move forward, it attaches one end on the ground and, with an undulating movement, draws the other end toward it.

1 The leech advances its front end and attaches it to the underlying surface. It then draws its rear end forward.

2 When its rear end reaches the attached front end, the leech attaches the rear end to the underlying surface, and the sequence of motions is repeated.

50,000

BREEDING FARM

THE ONLY FARM IN THE WORLD THAT SUPPLIES LEECHES IS LOCATED IN WALES, IN THE UNITED KINGDOM. IT HAS MORE THAN 50,000 LEECHES THAT ARE SHIPPED TO LABORATORIES AND HOSPITALS IN 30 COUNTRIES.

TYPES OF LEECHES

Leeches are classified according to how they feed. One group of leeches includes animals whose pharynx has no teeth and cannot be turned outward. A second group includes leeches whose pharynx is toothless but can be turned outward like an elephant's trunk, projecting out of the leech's mouth, and can be inserted into the host's soft tissues. The third group includes highly specialized leeches in which the pharynx cannot be turned outward but is armed with three chitinous jaws with serrated edges.

1 LEECHES

There are 600 species of leeches. Leeches usually have 34 segments, but they can have 17 or 31. They live mainly in freshwater environments, but a few live in saltwater, and some have adapted to life on land in warm, damp places.

2 EUROPEAN MEDICINAL LEECH

This leech is used in medicine to treat the congestion of veins in reconstructive and plastic surgeries. The bite causes a hemorrhage where the tissue graft is placed, imitating the circulation of the blood.

ELASTIC BODY

The segmented body of the leech allows it to move with undulating movements when necessary, for example, to walk. The leech can also put on a show when it is on alert in the presence of a host. At such times it manages to stand itself up on one of its ends.

SUCKER

The leech has two suckers, one at its front end, where the mouth and jaw are located, and another at the rear.

Glossary

Abdomen

Posterior portion of the body of arthropods consisting of similarly formed segments, containing the reproductive organs and a part of the alimentary canal. In insects and arachnids, it is the posterior section of the body.

Adaptation

A structural, physiological, or behavioral trait that allows an organism to live in its environment.

Ambulacral Groove

In echinoderms, any of the radial grooves through which the hydraulic system's tube feet protrude.

Anaerobe

An organism that can live without free oxygen.

Annelids

Animals with a long cylindrical body consisting of ring-formed segments.

Antennae

A pair of long sensory appendages on the head of many arthropods.

Arachnid

An eight-legged arthropod.

Arachnologist

A scientist who studies arachnids-spiders and related groups.

Arthropod

An animal with articulated appendages and a segmented body, covered by an exoskeleton.

Asexual Reproduction

Any reproductive process, such as the production of gemmae or the division of a cell or organism into two or more approximately equal parts, that does not involve gametes joining together.

Bilateral Symmetry

Corporal form whereby the right and left halves of an organism are approximate mirror images of each other.

Biology

The science that studies living organisms-their constitution, structure, function, and relations.

Brachyopods

A group of marine invertebrates whose soft body is protected by a shell consisting of two parts called valves.

Calcite

A form of the chemical compound calcium carbonate.

Carrion Eaters

An animal that feeds on dead animals it finds. Given the occasion, some large carnivores such as lions and hyenas can behave like carrion eaters.

Caste

A social group that carries out specific tasks, characteristic of ants and bees, among other insects.

Celoma

A cavity formed between layers of mesoderm in which the alimentary tract and other internal organs are suspended.

Cephalopod

A class of exclusively marine mollusks with tentacles or legs attached to the head. These appendages have rows of suckers that are used for capturing prey and copulation.

Cephalothorax

The head and thorax combined in one single body segment.

Chelicera

First pair of appendages in crabs, sea spiders, and arachnids, usually in the form of pincers or fangs.

Chitin

Tough, durable polysaccharide that contains nitrogen and is found in the exoskeleton of arthropods or other surface structures of many invertebrates, and also in the cell walls of fungi.

Class

One of the many divisions into which scientists classify animals. The invertebrates form a separate class of their own.

Classification

The process of establishing, defining, and ordering taxa within a hierarchical series of groups.

Cocoon

A protective sheath usually made of silk. Many insects make cocoons to protect themselves during the pupa stage, until they become adults.

Colony

A group of animals of the same species that live and work together to survive.

Community

The entire population of organisms that inhabit an environment in common and who interact with one another.

Compound Eye

In arthropods, a complex eye made of many separate units, each of which has light-sensitive cells and a lens that can form an image.

Crustacean

An animal of the arthropod group, with antennae and articulated appendages, that uses gills to breathe and has a body protected by a thick covering.

Cuticle

An organic, noncellular protective covering secreted by the epidermis.

Defecation

The part of an organism's digestive process that consists of eliminating undigested matter.

Dermis

The internal layer of the skin below the epidermis.

Deuterostoma

An animal in which the anus is formed in or near the developing embryo's blastophore zone, and whose mouth is formed afterward in another location; the echinoderms and the chordates are deuterostoma.

Dimorphism

One species that exists in two distinct forms.

Echinoderms

Invertebrate marine animals. The bodies of the adults have a pentagonal symmetry. Underneath the skin they have a calcareous skeleton with spines and protuberances. They have an internal hydraulic system, connected with ambulacral feet, that makes locomotion possible.

Endemic

Native to a particular geographical region and restricted to it.

Endoderm

One of the three layers of the embryonic tissue of animals; it originates in the epithelium that covers certain internal structures.

Epicuticle

The thin, outermost layer of the arthropod exoskeleton, consisting primarily of wax.

Epidermis

The outermost layer of cells.

Epithelial Tissue

Type of tissue that surrounds a body or structure or covers a cavity. Epithelial cells form one or more regular layers with little intercellular material.

Etology

The comparative study of animal behavior in its natural habitat, and the evolutionary, genetic, ecological, and physiological factors that influence its manifestation.

Evolution

The changes in the genetic reservoir from one generation to the next, as a consequence of processes such as mutation or natural selection, among other things.

Exoskeleton

The external covering supporting the body, commonly found in arthropods. It is like an articulated shell made of chitin; it serves as a support for muscles and the soft internal organs.

Eyelet

Simple light receptor, common among invertebrates.

Family

A category in taxonomy that groups genus together; lower than order and higher than genus.

Fossil

The preserved remains of an organism that disappeared a long time ago.

Gamete

The mature reproductive cell that combines with a gamete of the opposite sex to form a zygote that is usually diploid; male gametes are called spermatozoids and female gametes are called ovules.

Gastrovascular Cavity

A digestive cavity with an opening, characteristic of the phyla Cnidaria and Ctenophora. It has digestive and circulatory functions.

Genus

A category in taxonomy that groups species together.

Geotropism

A directional response to gravity.

Gonopore

A pore in the reproductive apparatus through which gametes pass.

Hemocell

A blood-filled cavity inside the tissues; characteristic of animals with an incomplete circulatory system, such as mollusks and arthropods.

Hermaphrodite

An organism that has both reproductive systems, male and female; hermaphrodites may or may not self-fertilize.

Hormone

An organic molecule, secreted in small amounts by one part of an organism, that regulates the function of other tissue or organs.

Host

An organism in which a parasite lives.

Hydrostatic Skeleton

A skeleton in which fluid is contained by muscular walls that transfer the force from one part of the body to another when subjected to pressure.

Invasive

Relating to a species or organism that was brought into an environment and harms biodiversity, agricultural or fishing productivity, or human health.

Invertebrate

Animal without a spinal column. Some, such as worms, have soft bodies. Others, such as arthropods, are protected by a hard exoskeleton.

Kingdom

Taxonomic category that includes phyla or divisions. Until the appearance of the category of domain, the kingdom was the highest-level category in biological classification.

Larva

Animal in a developmental stage, after leaving the egg. It can feed itself but has not yet acquired the shape and structure of the adults of its species.

Mandible

Appendage immediately below the antennae, used to trap, hold, bite, or chew food.

Mantle

In mollusks, the outer layer of the body wall or a soft extension of it. It usually secretes a shell.

Medium

Element or substrate where organisms live.

Mesoderm

The middle layer of the three layers of embryonic tissue.

Metamorphosis

Abrupt transition from the larval form to the adult form.

Metazoa

Main group in the animal kingdom (including mollusks, annelids, and arthropods) in which the mouth is formed at or near the blastula in the developing embryo.

Microorganism

Organism that can be seen only with a microscope.

Migration

Seasonal travel of animals from one region to another to reproduce or to seek food, better climate, or better living conditions in general.

Mimetism

Property of certain animals and plants to resemble living things or inanimate objects that live nearby, mostly by means of color.

Mollusk

Invertebrates of the phylum Mollusca, with a soft body divided into a head, foot, and visceral mass. They have a fold called a mantle that envelops all or part of the body.

Molting

Removal of all or part of the outer covering of an organism; in arthropods, a periodic changing of the exoskeleton that enables them to grow in size.

Nutrients

Chemical elements essential for life. Examples are carbon, oxygen, nitrogen, sulfur, phosphorus, magnesium, and potassium.

Ommatidium

The simple visual unit of a compound eye in arthropods; it contains light-sensitive cells and a lens that can form an image.

Omnivore

Living being that feeds on plants and animals.

Order

Taxonomic category that includes families; category lower than a class and higher than a family.

Organ

Body part made of various tissues grouped into a structural and functional unit.

Organic Material

Animal or plant material in any stage of decomposition, found on or within the soil.

Organism

Any living creature, whether single-celled or multicellular.

Parasite

Organism that lives at the expense of another.

Phylum

Taxonomic category that includes classes; category lower than a kingdom and higher than a class.

Plankton

Group of small living beings, whether plants (phytoplankton) or animals (zooplankton), that live suspended in freshwater or ocean water.

Planula

Type of unattached, ciliated larva of many organisms of the phylum Cnidaria (jellyfish, sea anemones, and coral).

Polyp

The immobile stage in the life cycle of animals of the phylum Cnidaria.

Population

Group of individuals of the same species that live in a certain area during a specific time.

Predator

Organism that feeds on other living beings.

Pseudocoelom

Body cavity consisting of a fluid-filled space between the endoderm and the mesoderm, characteristic of nematode worms.

Pseudopod

Temporary cytoplasmic projection of an amoeboid cell whose movement and feeding occur through phagocytosis.

Radial Symmetry

The regular disposition of body parts around a central axis in such a way that any plane that cuts through the axis divides the organism in halves that constitute mirror images of each other. It is seen in adult echinoderms.

Safety Thread

A silk thread that a spider leaves behind when it is moving, attaching it from time to time to various surfaces.

Salinity

Measurement of the amount of common salt in water or soil. Common salt is a sodium salt, sodium chloride, common in nature, that gives a salty flavor to ocean water and salt lakes.

Segmentation

Successive cell divisions in the egg of an animal to form a multicellular blastula.

Sexual Dimorphism

An assembly of external morphological characteristics that make it possible to distinguish the males from the females of the same species.

Sexual Reproduction

Reproduction involving meiosis and fertilization.

Social Insects

Insects that live with others of the same species, looking after the young and gathering food for the community.

Species

A group of individuals that recognize one another as belonging to the same reproductive unit.

Spiracle

One of the external openings of the respiratory system in terrestrial arthropods.

Statocyst

A balance organ consisting of a sac-like structure that contains grains of sand (statoliths) or some other material that stimulates the sensory cells when the organism is in motion.

Substrate

The surface that constitutes an organism's habitat or life support.

Swarm

Insects that act in a group for eating, mating, or finding a new location for a nest.

Tagmosis

The process of segment formation (metameres) into corporal regions (tagmata) with differentiated functions.

Taxism

Also known as taxia, it is the orientation of movement in those organisms that, being able to move freely from one place to another, track their course in the direction of an external stimulus.

Taxonomy

Study of the principles of scientific classification. The organization, grouping, and denomination of living things.

Tentacles

Long and flexible organs located around the mouth of many invertebrates, often prehensile and tactile.

Thorax

In crustaceans and insects, the fused segments located between the head and the abdomen to which the legs are attached.

Tissue

Group of similar cells organized in a structural and functional unit.

Trachea

In insects and some other terrestrial arthropods, the system of air conduits covered with chitin.

Venom

Chemical agent injected into other animals in order to kill or paralyze them, or to ward off an attack.

Zoology

Discipline or science dedicated to the study of animals.

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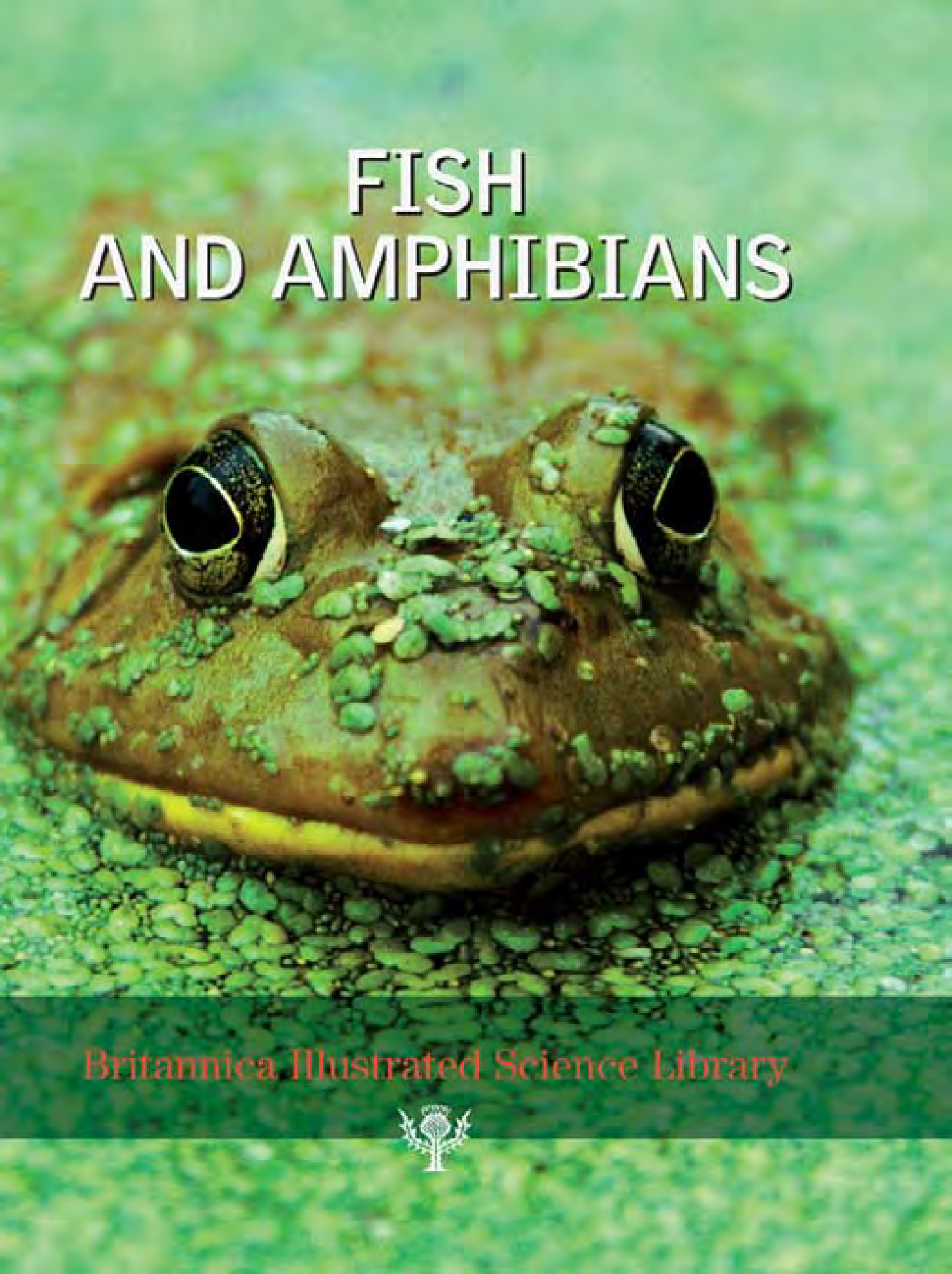

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FISH AND AMPHIBIANS

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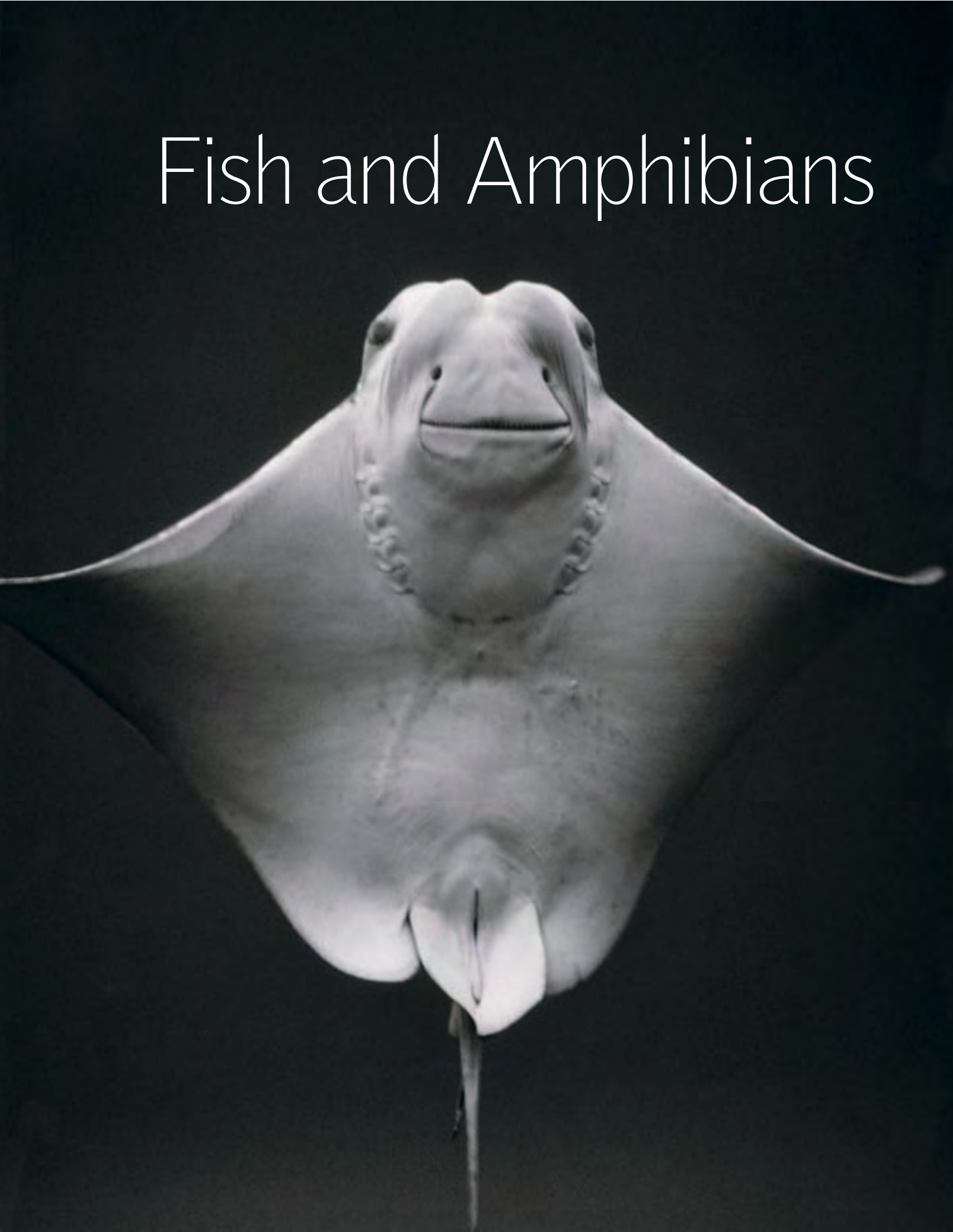

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VIETNAM
Along this country's nearly 200 miles (300 km) of coastline live great numbers of people who depend on fishing and coral reefs for their livelihood.

Water, the Source of Life

The life of marine creatures is fascinating and has always been closely linked to human life. This is so particularly because fishing has been the livelihood of islanders through the years. Yet for some time, in many areas of the world—such as Nha Trang Bay, on the south coast of Vietnam—this activity has been in a state of crisis. In Nha Trang Bay the growth of outside investment in aquaculture has limited the economic opportunities of the local population, including fishing for squid and other species in the reefs with hook and line. In other cases, commercial fishing endangers the future of those who rely on traditional fishing methods to make a living. This is only one of the topics explored in this book, which also relates in detail many secrets of these vertebrates, which were among the first creatures with skeletons to appear on the Earth. Perhaps knowing more about their habits and modes of life may move us to care for them and protect them. They are at the mercy of variations in water conditions to a greater extent than humans.

Humans have marveled for centuries at the fact that, after journeying across the ocean, salmon can find the river where they were born. Is this navigational ability related to the Earth's magnetic field, sense of smell, instinct, or something else that humans cannot even imagine? For those interested in statistics, in the Yukon River in Alaska and in Canada, certain tagged Chinook salmon covered nearly 2,000 miles (3,200 km) in 60 days. Upon entering the river, the salmon stop eating and utilize the fat they accumulated while in the ocean. After laying their eggs, many of the females die. Most ocean fish seek shallow, nutrient-rich waters in which to lay their eggs. That is why coastal waters and estuaries are so important to the life cycle of many species. Another oddity of these animals is that they have adapted to living in a variety of aquatic habitats: rivers, lakes, estuaries, coral reefs, and the open sea. For this reason, they have developed various survival techniques to live in such a wide variety of places.

Despite the fact that lunglike sacs evolved because of the difficulty of breathing with gills in water with low oxygen content, the development of these sacs was also the first step toward moving onto land. Some descendants of the first fish with fleshy, jointed fins, known as lobe-fin fishes, began to find terrestrial food sources and, with time, adapted more completely to life on the planet's surface. This evolutionary change—passing from an aquatic to a terrestrial medium—constituted a true revolution for the life-forms that existed up until then. The amphibians we will show you in this book that are living today are a tiny representation of all those that appeared during the Devonian Period, most of which became extinct during the Triassic Period.

Amphibians, especially some frog species, have become true specialists in the art of mimicry. One of the most fascinating examples is the European tree frog, which changes color to regulate its body temperature. On warm, dry evenings the frog rests in sunny places, and its skin is pale. As its surroundings become cooler, the frog darkens to absorb heat. Although amphibians are masters of camouflage, which protects them from predators, at present they are the object of worldwide concern because of the dramatic decline in their populations. Turn the page, and you will discover much more about the abilities of fish and amphibians, extraordinary creatures that live right next to us. ●

General Characteristics

CROCODILE FISH FIN
This fish, which lives in waters with abundant coral reefs, can grow up to 21 inches (54 cm) long.

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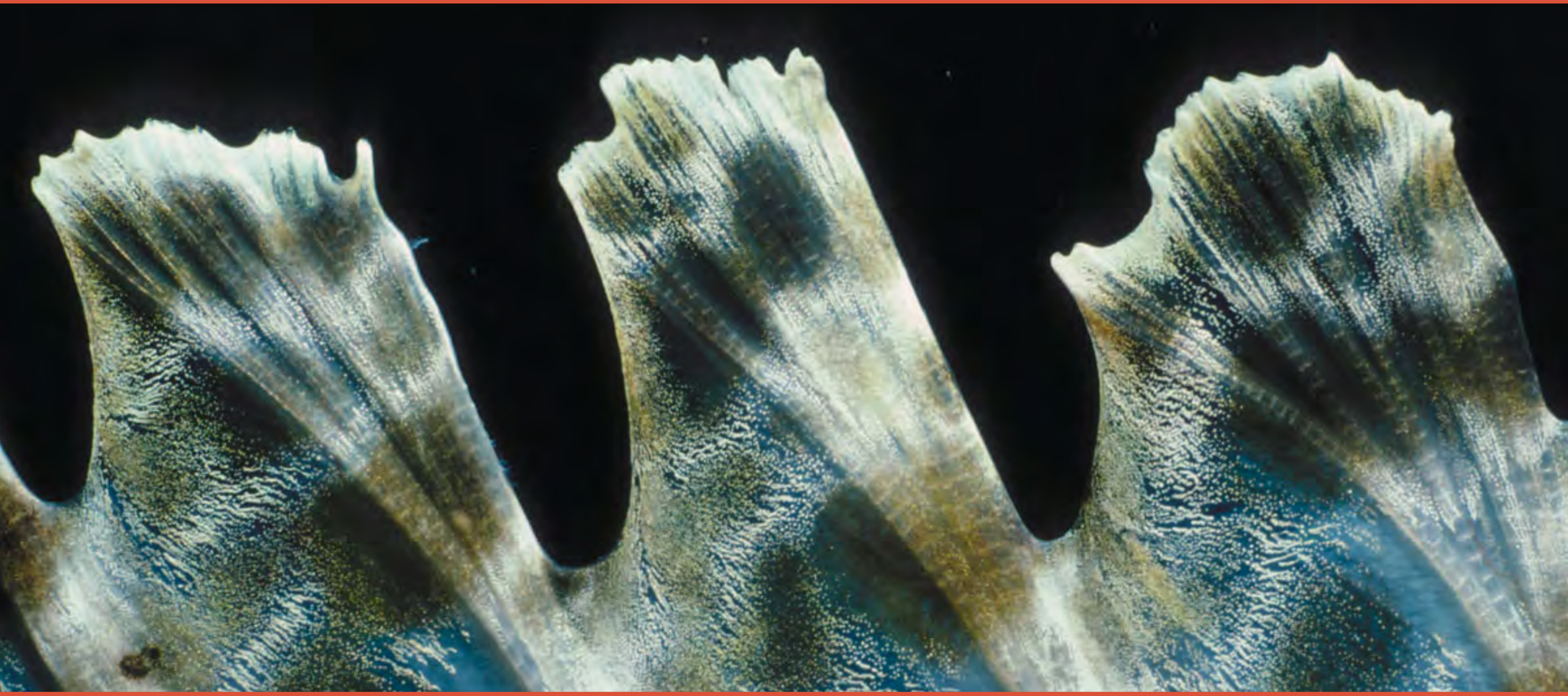


Fish were the first vertebrates with bony skeletons to appear on the Earth. They doubtless form the most numerous group of vertebrates. Unlike today's fish, the earliest fish had no scales, fins, or jawbone, but they did have a type of dorsal fin. Over time they have been changing in form and size to adapt to different environments, in both fresh water and salt water. Their bodies are generally streamlined, being covered with smooth scales and having fins that enable them to move with energy, direction, and stability. In place of lungs, these complex creatures normally breathe through gills that capture oxygen dissolved in the water, and they are cold-blooded. ●

Earliest Forms

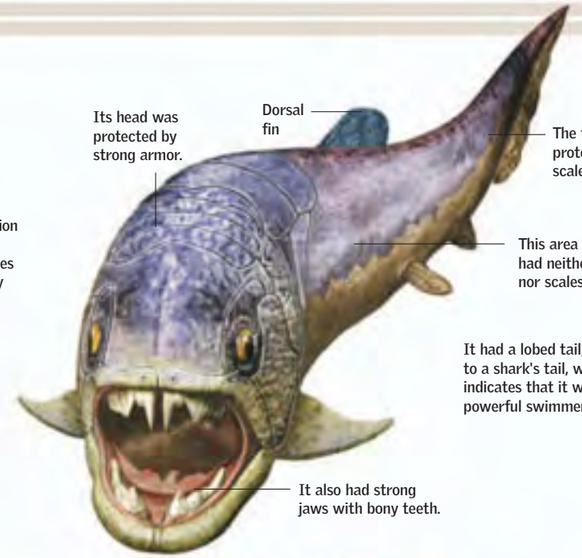
About 470 million years ago, the first fish appeared. Unlike today's fish, they did not have a jawbone, fins, or scales. Hard plates covered the front part of the fish and formed a protective shield. They also had a solid, flexible dorsal spine that allowed them to propel themselves. Later, in the Silurian Period, fish appeared that had a jawbone. Known as the gnathostomata, they were large predators.

STREAMLINED SHAPE
The shape of Pteraspis shows that it was an excellent swimmer.

Dunkleosteus

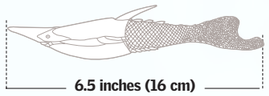
The Arthrodira—with a jointed neck—were armored fish that predominated in the late Devonian Period. The Devonian predator Dunkleosteus was an arthrodiran placoderm that lived over 300 million years ago. Its head was encased in an impressive set of plates 1.2 inches (3 cm) thick, with razor-sharp bony plates that served as teeth.

FIERCE JAW
Dunkleosteus was a fierce predator that devoured any type of prey, including sharks.



Pteraspis

The fish without a jawbone, Pteraspis, was about 6.5 inches (16 cm) long and lived in the seas of Europe, Asia, and North America. These fish were most abundant during the Devonian Period. They had bodies with armor that covered their heads, and they had a streamlined shape. The shell had a conical nose that helped the fish to move.



WING SHIELD

Scientific name	Pteraspis
Diet	Small organisms
Habitat	Sea, then rivers and lakes
Range	Europe, Asia, North America
Period	Early Devonian

CONICAL NOSE
Its streamlined shape helped the fish move.

EYES
Very small, located on both sides of the head.

DORSAL SPIKE
Located on the fish's back, it worked like a dorsal fin.

DORSAL SPINES
These helped the fish to stay balanced while swimming.

MOUTH
Having no jawbone, they fed on small organisms.

LATERAL LINE
Sensory organs are present on both sides of the body and on top of the armor.

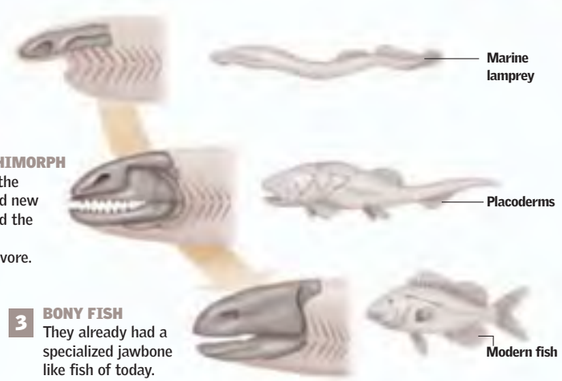
TAIL
The shape of the tail helped balance the weight of the armor.

16 feet (5 m)
LENGTH OF THE FISH

EVOLUTION OF THE JAWBONE

The development of the jawbone was a long evolutionary process that involved changes in the diet of fish to include not only small organisms but also other fish.

cranium
The evolution of the jawbone modified the configuration of the skull.



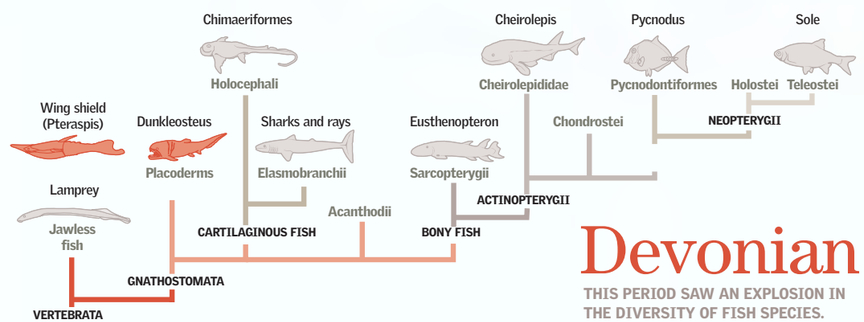
Fossil

Fish with lungs appeared in the Mesozoic Era (200 million years ago). Similar to amphibians, these species breathe with lungs and are now considered living fossils. The line through the center of the photo of the fossil is the fish's lateral line.

FOSSILIZED LUNGFISH SCALES
Dipterus valenciennesi

Evolution

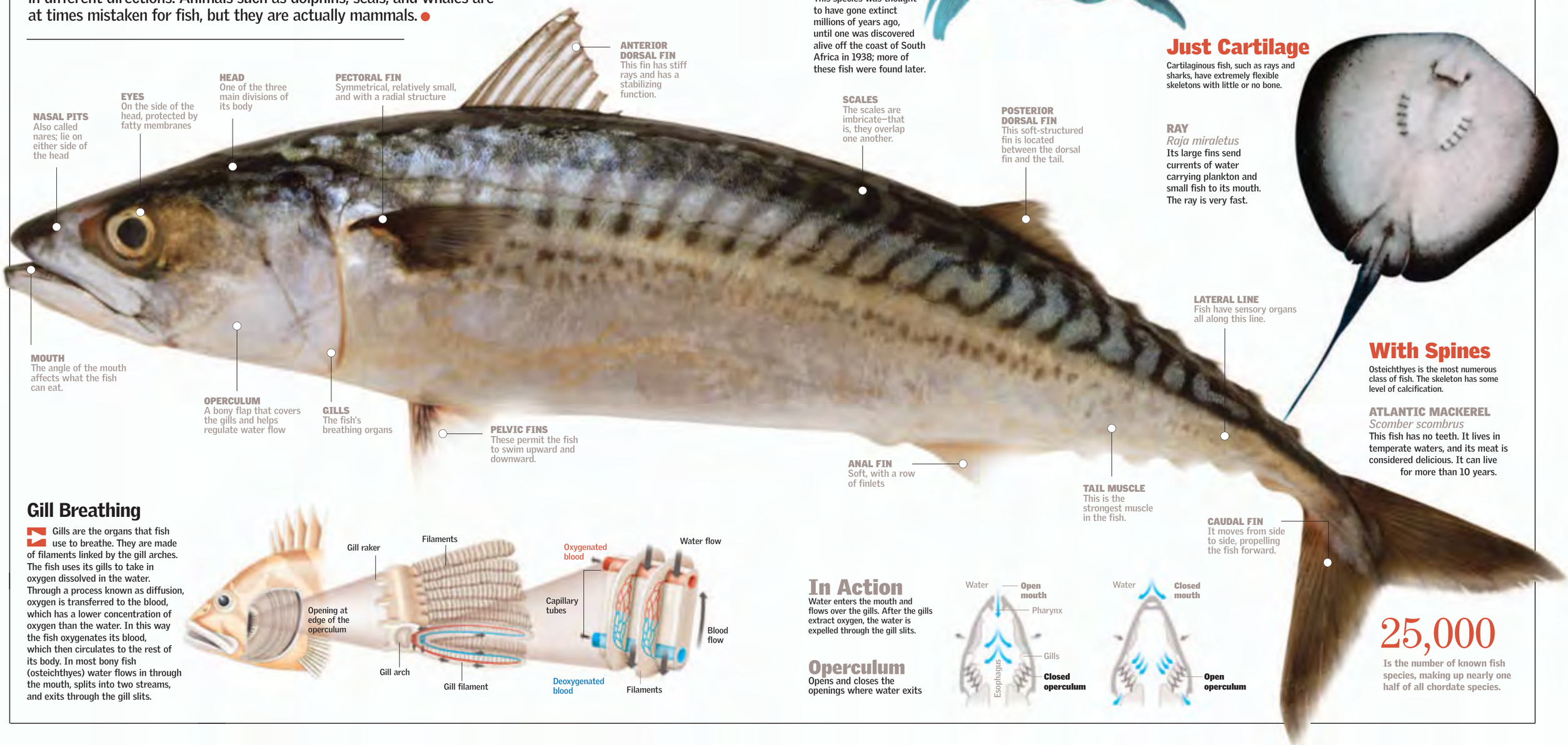
In the Devonian Period ocean fish began to diversify. Coelacanths appeared, as well as the earliest bony fish and the first cartilaginous fish, including sharks. In this period the three main groups of gnathostomad fish also appeared: the placoderms, chondrichthyes, and osteichthyes.



Devonian
THIS PERIOD SAW AN EXPLOSION IN THE DIVERSITY OF FISH SPECIES.

Distinguishing Features

Similar characteristics define nearly all fish, with a few rare exceptions. These aquatic animals are designed to live underwater, and they have a jawbone and lidless eyes and are cold-blooded. They breathe through gills and are vertebrates—that is, they have a spinal column. They live in the oceans, from the poles to the equator, as well as in bodies of fresh water and in streams. Some fish migrate, but very few can pass from salt water to fresh water or vice versa. Their fins enable them to swim and move in different directions. Animals such as dolphins, seals, and whales are at times mistaken for fish, but they are actually mammals.



Near-fossils

Choanichthyes (Sarcopterygii) are archaic bony fish with fleshy fins. Some of them were the first animals with lungs. Only a few species survive.

COELACANTH
Latimeria chalumnae
This species was thought to have gone extinct millions of years ago, until one was discovered alive off the coast of South Africa in 1938; more of these fish were found later.

Jawless Fish

Of the ancient agnathans, considered the first living vertebrates, only lampreys and hagfish are left.

SEA LAMPREY
Lampetra sp.
Its round, toothed mouth allows it to suck the blood of fish of various species. There are also freshwater lampreys.

Just Cartilage

Cartilaginous fish, such as rays and sharks, have extremely flexible skeletons with little or no bone.

RAY
Raja miraletus
Its large fins send currents of water carrying plankton and small fish to its mouth. The ray is very fast.

With Spines

Osteichthyes is the most numerous class of fish. The skeleton has some level of calcification.

ATLANTIC MACKEREL
Scomber scombrus
This fish has no teeth. It lives in temperate waters, and its meat is considered delicious. It can live for more than 10 years.

Gill Breathing

Gills are the organs that fish use to breathe. They are made of filaments linked by the gill arches. The fish uses its gills to take in oxygen dissolved in the water. Through a process known as diffusion, oxygen is transferred to the blood, which has a lower concentration of oxygen than the water. In this way the fish oxygenates its blood, which then circulates to the rest of its body. In most bony fish (osteichthyes) water flows in through the mouth, splits into two streams, and exits through the gill slits.

In Action

Water enters the mouth and flows over the gills. After the gills extract oxygen, the water is expelled through the gill slits.

Operculum

Opens and closes the openings where water exits

25,000

Is the number of known fish species, making up nearly one half of all chordate species.

Bony Fish

The group of fish that have evolved and diversified most in the last few million years are the osteichthyes, fish with spines and jawbones. In general, their skeletons are relatively small but firm, being made mostly of bone. Flexible fins enable them to control their movements with precision. The various species of osteichthyes have adapted to a wide variety of environments and even to extreme conditions.

Solid Structure

The skeleton of a bony fish is divided into the cranium, spinal column, and fins. The opercula, which cover their gills, are also made of bone. The cranium holds the brain and supports the jawbone and gill arches. The vertebrae of the spine are jointed; they provide support to the body and join the ribs at the abdomen.

UPPER JAW

LACRIMAL BONE

CRANIUM

LOWER JAW

EYE SOCKET

OPERCULAR BONES protect the gills.

CLAVICLE

PECTORAL FIN

PELVIC FIN

PERCH
Perca fluviatilis
The skeleton, along with the bony structure of the fins

FIRST DORSAL FIN

SECOND DORSAL FIN

RIB

INTERHEMAL (VENTRAL) SPINES support the spiny rays of the anal fin.

SPINY RAYS OF ANAL FIN

CAUDAL FIN propels the fish through the water.

OCEAN SUNFISH
Mola mola
The largest osteichthian fish, it can grow to be 11 feet (3.3 m) long and can weigh 4,000 pounds (1,900 kg).

The Swim Bladder

An appendage of the intestines that regulates flotation by filling with and emptying itself of gas. The gas enters through a gland that extracts the gas from a net of capillaries, called the rete mirabile, and it leaves the bladder through a valve that causes it to dissolve back into the blood.

EMPTY
When the fish empties its swim bladder, it sinks.

FULL
By reducing its density, the fish rises.

Rete Mirabile

Dorsal Aorta

Gas Gland

SWIM BLADDER

VERTEBRA

Neural spine

Neural arch

Centrum

Hemal arch (chevron)

Hemal spine

VERTEBRAL COLUMN
The main nerves and blood vessels run above and below the bony center of the spine.

CAUDAL FIN VERTEBRAE

Actinopterygii

The main characteristic of actinopterygian fish is their bony skeleton, with bony spines in their fins. They have a cartilaginous skull (partly calcified) and only one pair of gill openings covered by an operculum.

THERE ARE OVER
480
FAMILIES

PERCH
Perca fluviatilis

SCALES
They overlap and are covered with mucus.

CYCLOID

CTENOID

GANOID

Sarcopterygii

Another name for the Choanichthyes, a subclass of bony fish. Their fins, like the fins of whales, are joined to the body by means of fleshy lobes. In lungfish, these lobed fins look like filaments.

COELACANTH
Latimeria chalumnae

DETAIL OF FLESHY FIN

Cartilaginous

As indicated by the name, the skeleton of cartilaginous fish is made of cartilage, a flexible, durable substance that is softer than bone. They have jaws and teeth, which are usually hard and sharp. Their body is covered with hard scales. However, they lack a characteristic shared by most bony fish—the swim bladder, an organ that helps fish to float. Their pectoral fins, tail, and flat head give this group a streamlined profile.

Sharks

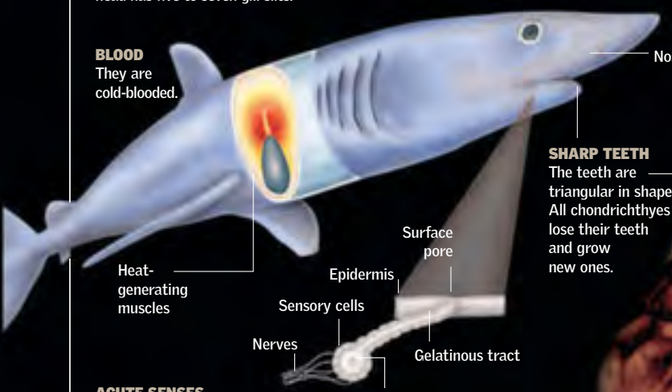
These fish live in tropical waters, although some do inhabit temperate waters or fresh water. They have an elongated, cylindrical shape and a pointed snout, with the mouth on the underside. Each side of their head has five to seven gill slits.

2,650 pounds (1.2 metric tons)

NORMAL WEIGHT OF A SHARK (*SUPERORDER SELACHIMORPHA*)

LIGHT AND FLEXIBLE
The skeleton is very flexible, but the spinal column of cartilage is firm, with mineral deposits.

SPINAL COLUMN

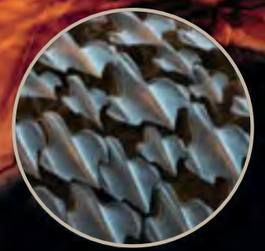


BLOOD
They are cold-blooded.

SHARP TEETH
The teeth are triangular in shape. All chondrichthyes lose their teeth and grow new ones.

GILL SLITS
These life-forms may have five or six gill slits.

ACUTE SENSES
Chondrichthyes have ampullae of Lorenzini, acutely sensitive lateral lines, and a highly developed sense of smell.



SCALES
Most of these fish have skin with thousands of interlocking scales, called denticles or placoid scales.

HOW IT REPRODUCES
The modified pelvic fin of the male is its sexual organ. The fin penetrates the female, which then lays a string of eggs. The young are not born in larval form.

IN SOME SHARK SPECIES, THE YOUNG DEVELOP WITHIN THE FEMALE, INSIDE A STRUCTURE SIMILAR TO A PLACENTA.

HETEROCERCAL TAIL
The shark's caudal fin is small, and the upper lobe is larger than the lower lobe.

SHARK
Superorder Selachimorpha
This X-ray shows the spine and nerves.

Primitive

The ancient origin of Chondrichthyes contrasts sharply with their highly evolved senses. This is a fossilized cartilage vertebra of a shark from the Paleozoic Era, between 245 and 540 million years ago. It was found in a fossil deposit in Kent, England. The blood of sharks has a high concentration of urea, which is presumed to be an adaptation to salt water and constitutes a fundamental difference between sharks and their freshwater ancestors.

Manta Rays and Skates

These fish have two pectoral fins joined on the front of the body. They use them to swim, giving the impression that they fly in the water. The rest of the body moves similarly to a whip. Their eyes are located on the upper side of the body; the mouth and gills are on the lower side.

RAY
Raja clavata (Thornback Ray)
This species lives in cold oceans in depths up to 660 feet (200 m).

Rays may have five or six rows of gills; chimaeras have only one.

Chimaerae

Deepwater fish. Like the prehistoric animals, they have large heads and pectoral fins. They have a spine in front of the first dorsal fin. The back end of the body narrows into a tail followed by a thin filament.

CHIMAERAS
Rhinochimaera pacifica
This fish lives in the dark at depths of up to 4,900 feet (1,500 m); it is 4 feet (1.2 m) long.

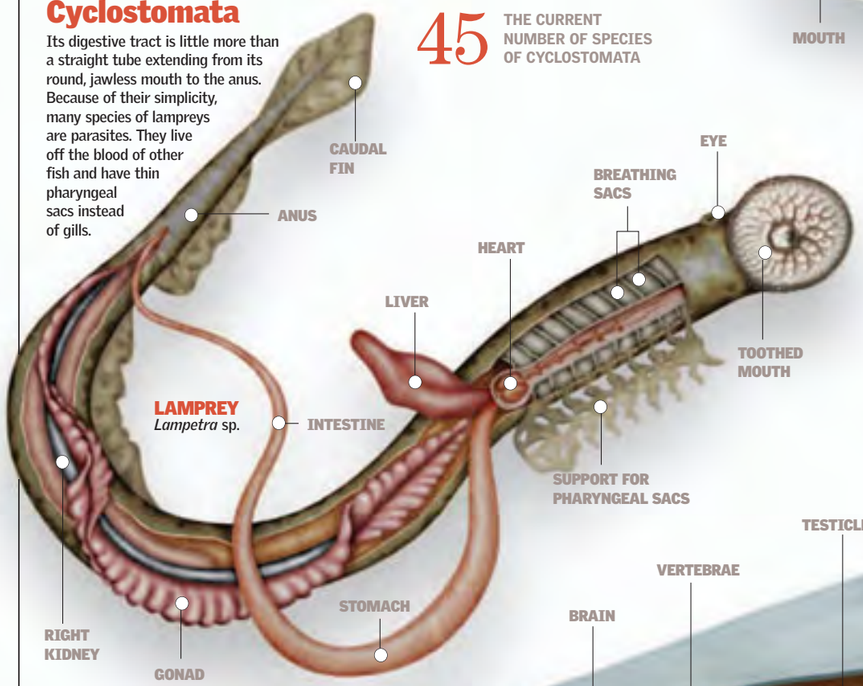
Anatomy

Most fish have the same internal organs as amphibians, reptiles, birds, and mammals. The skeleton acts as a support, and the brain receives information through the eyes and the lateral line to coordinate the motions of the muscles in propelling the fish through the water. Fish breathe with gills, they have a digestive system designed to transform food into nutrients, and they have a heart that pumps blood through a network of blood vessels.

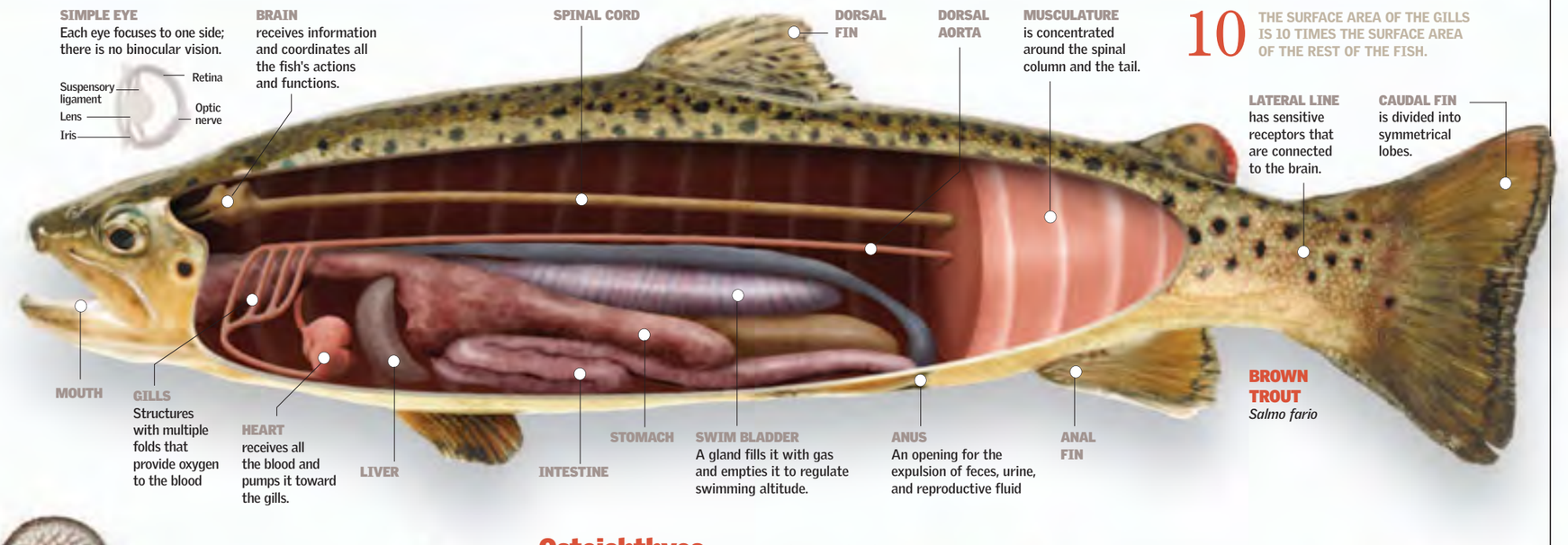
Cyclostomata

Its digestive tract is little more than a straight tube extending from its round, jawless mouth to the anus. Because of their simplicity, many species of lampreys are parasites. They live off the blood of other fish and have thin pharyngeal sacs instead of gills.

45 THE CURRENT NUMBER OF SPECIES OF CYCLOSTOMATA



LAMPREY
Lampetra sp.



BROWN TROUT
Salmo fario

10 THE SURFACE AREA OF THE GILLS IS 10 TIMES THE SURFACE AREA OF THE REST OF THE FISH.

Osteichthyes

Typically, their organs are compressed in the lower front quarter of the body. The rest of their internal structure consists mainly of the muscles that the fish uses to swim. Some bony fish, such as carp, have no stomach but rather a tightly coiled intestine.

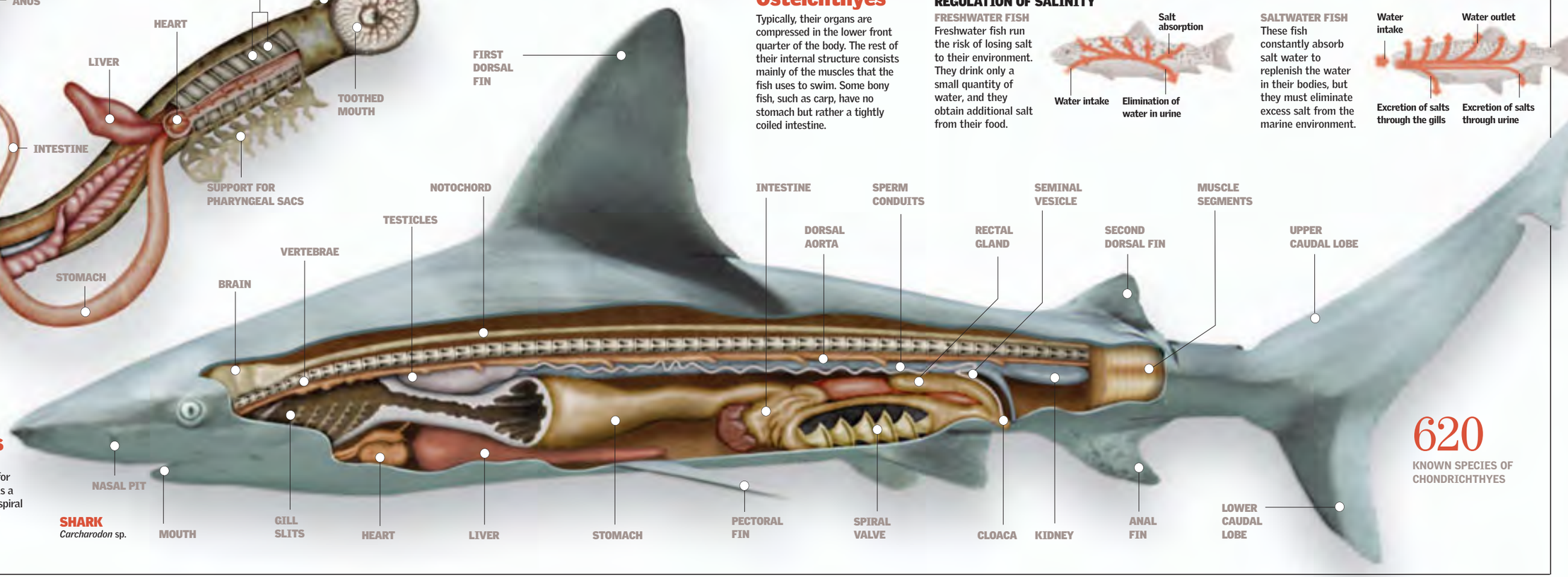
REGULATION OF SALINITY

FRESHWATER FISH
Freshwater fish run the risk of losing salt to their environment. They drink only a small quantity of water, and they obtain additional salt from their food.

SALTWATER FISH
These fish constantly absorb salt water to replenish the water in their bodies, but they must eliminate excess salt from the marine environment.

Chondrichthyes

A shark has the same organic structures as a bony fish, except for the swim bladder. A shark also has a corkscrew-like structure called a spiral valve at the end of its intestine to increase the surface area for absorption of nutrients.



SHARK
Carcharodon sp.

620 KNOWN SPECIES OF CHONDRICHTHYES

Life in the Water

GLOBEFISH
When threatened, this strange animal reacts by swallowing water until it blows up like a balloon.

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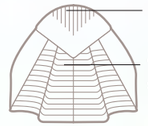
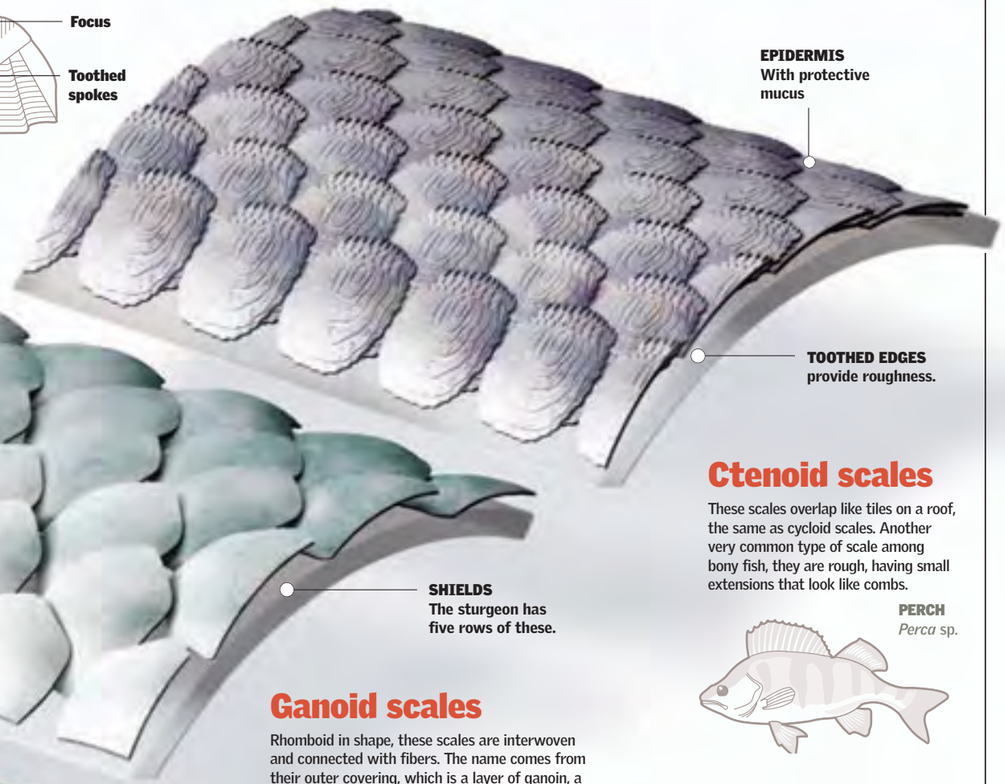
The idea that fish are blind is wrong. Most fish have the best possible eyesight for their habitat. Further, they can see in color and use colors to camouflage themselves or defend their territory. Most fish can vary their coloring when something changes in their environment. Silverfish, common in all freshwater habitats, have dark backs (ranging from greenish brown to dark blue), but the sides of their bellies are silvery white. When viewed from above, their backs become confused with the deep hues of the river water or even with the crystalline blue of lakes. Seen from below, the lower part becomes confused with bright reflections in the water. ●

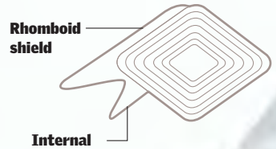
Protective Layer

Most fish are covered with scales, an external layer of transparent plates. All fish of a given species have the same number of scales. Depending on the family and genus of a fish, its scales can have a variety of characteristics. Scales on the lateral line of the body have small orifices that link the surface with a series of sensory cells and nerve endings. It is also possible to determine a fish's age by studying its scales.

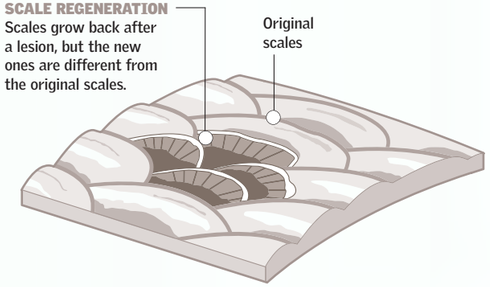
FOSSILIZED SCALES
The remains of these thick, shiny, enameled scales belong to the extinct genus *Lepidotes*, a fish that lived during the Mesozoic Era.

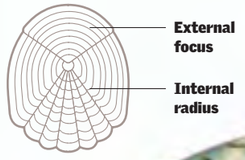






SCALE REGENERATION
Scales grow back after a lesion, but the new ones are different from the original scales.



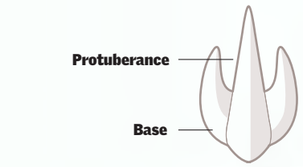


Ctenoid scales

These scales overlap like tiles on a roof, the same as cycloid scales. Another very common type of scale among bony fish, they are rough, having small extensions that look like combs.

PERCH
Perca sp.

AGE BY SCALES
A fish does not add new scales as it grows, but the scales it has increase in size. In this way growth rings are formed, and the rings reveal the age of the specimen.



EDGES
are overlapping, with a smooth texture.

TOOTHED SCALE
With enamel

CUTICLE
has a mucous consistency.

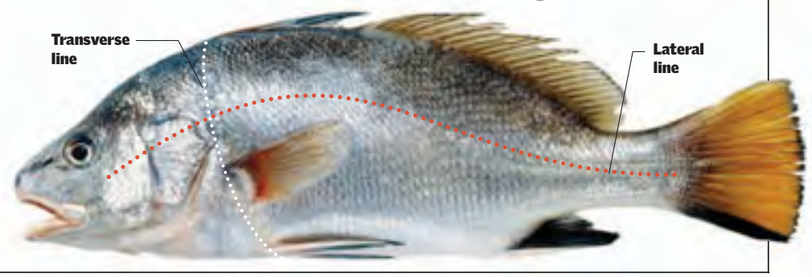
BASAL PLATE
A smooth, enameled surface

Ganoid scales

Rhomboid in shape, these scales are interwoven and connected with fibers. The name comes from their outer covering, which is a layer of ganoin, a type of shiny enamel. Sturgeon and pipefish have scales of this type.

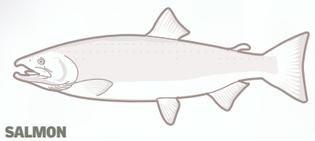
STURGEON
Acipenser sturio

DISTRIBUTION OF SCALES
Most scales occur in rows that slant diagonally downward and back. Species can be accurately identified by the number of rows (as counted along the lateral line), among other characteristics.



Cycloid scales

One of the most common types of scales among bony fish, the cycloid scales are organized so that the exposed surfaces overlap, forming a smooth and flexible cover. They are round with a soft, exposed surface, such as those of carps and silversides.



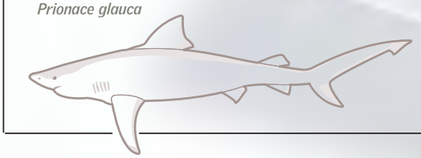
SALMON
Family Salmonidae

RED SNAPPER
Lutjanus campechanus

Placoid Scales

Typical of cartilaginous fish and other ancient species, these scales are made of pulp, dentine, and enamel, similar to the composition of teeth, and they have small extensions. The scales are usually very small and extend outward.

BLUE SHARK
Prionace glauca

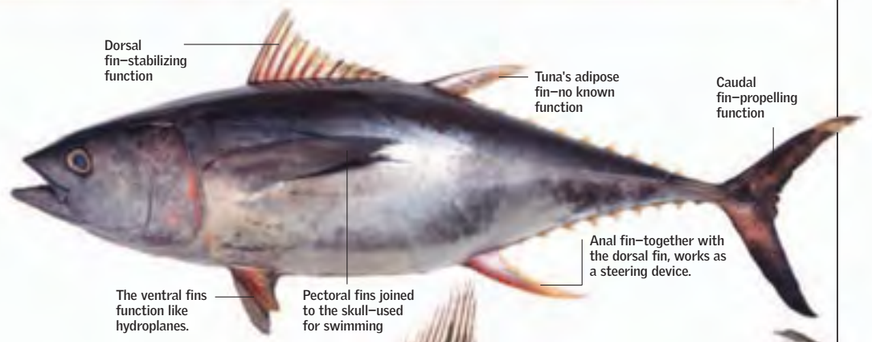


Extremities

A fish can control its motion, direction, and stability by means of its fins and tail. Anatomically these are extensions of the skin beyond the body and, in most bony fish, are supported by rays. The fins reveal much about the life of each fish. Thin fins with a split tail indicate that the animal moves very quickly, or it may need them to cover great distances. On the other hand, fish that live among rocks and reefs near the ocean floor have broad lateral fins and large tails.

An Integrated Team

In general, fish have seven fins: three single fins (dorsal, caudal, and anal) and two sets of paired fins (pelvic and pectoral). Each fin has specific functions related to the fish's movement. In all bony fish, the fins are made of bony rays and not of flesh. Tuna and a few other fish have one extra fin between the dorsal and caudal fins. Their thin lateral fins indicate that they can swim at high speeds. Others, such as the roosterfish (*Nematistius pectoralis*), have huge dorsal and ventral fins, and their main function is different: they are used to scare off potential predators.



SIAMESE FIGHTING FISH
Betta splendens
spreads its fins like a fan when it jumps.

FIN RAYS
Bony filaments that are joined by a membrane

GOLDFISH
Carassius auratus
A species bred for its beauty. Its tail can have eight different shapes.

SALMON
Salmo genus
Large dorsal and anal fins with pointed ends

HALF-MOON SHAPE
To provide speed

GOLDFISH
Carassius auratus
Bright and colorful, highly prized by aquariums

AFRICAN LUNGFISH
Protopterus annectens
There are four extant species of this fish and few specimens, but they proliferated during the Devonian Period.

FILAMENTS
Short and symmetrical above and below

Homocercal Tail

The caudal fin is divided into two equal lobes, an upper and a lower lobe, which extend from the end of the spinal column.

1/8 The proportion of the length of a salmon's homocercal tail with respect to its body.

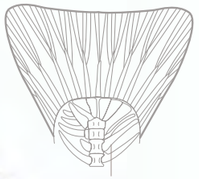
The Typical Tail

The vast majority of bony fish have homocercal tails.

Heterocercal Tail

Its two lobes are uneven. The dorsal spine turns upward in the highest lobe, and the rays that form the two lobes of the caudal fin extend from the lower end of the spinal column.

The highest and longest lobe turns upward.



The spinal column ends in a broadened structure.

GREY REEF SHARK
Carcharhinus amblyrhynchos
The heterocercal tail is typical of these cartilaginous fish, as well as of sturgeons.

The shark's spine extends into the upper lobe of the caudal fin.

1/3 The proportion of the lower lobe of the tail to the upper lobe of the tail

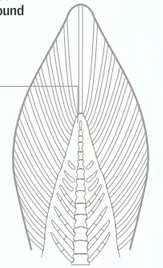
The lower lobe is smaller and is merely a projection to the side of the spine.

Diphycercal Tail

This kind of tail ends in a point; the spinal column reaches to the end, and the tail is surrounded above and below by a soft caudal fin. This very rare form is found on some sharks and hakes and in archaic bony fish.

The dorsal spine extends to the tip of the fin.

1/4 The length of the tail in relation to the rest of the body



The Art of Swimming

To swim, fish move in three dimensions: forward and back, left and right, and up and down. The main control surfaces that fish use for maneuvering are the fins, including the tail, or caudal fin. To change direction, the fish tilts the control surfaces at an angle to the water current. The fish must also keep its balance in the water; it accomplishes this by moving its paired and unpaired fins.

UPSIDE-DOWN CATFISH
Synodontis nigriventris

This fish swims upside down, seeking food sources that are less accessible to other species.

MUSCLES
The tail has powerful muscles that enable it to move like an oar.

GREAT WHITE SHARK
Carcharodon carcharias

Red muscles are for slow or regular movements.

Larger white muscles are for moving with speed, but they tire easily.

1 Starting Out

The movement of a fish through the water is like that of a slithering snake. Its body goes through a series of wavelike movements similar to an S curve. This process begins when the fish moves its head slightly from side to side.

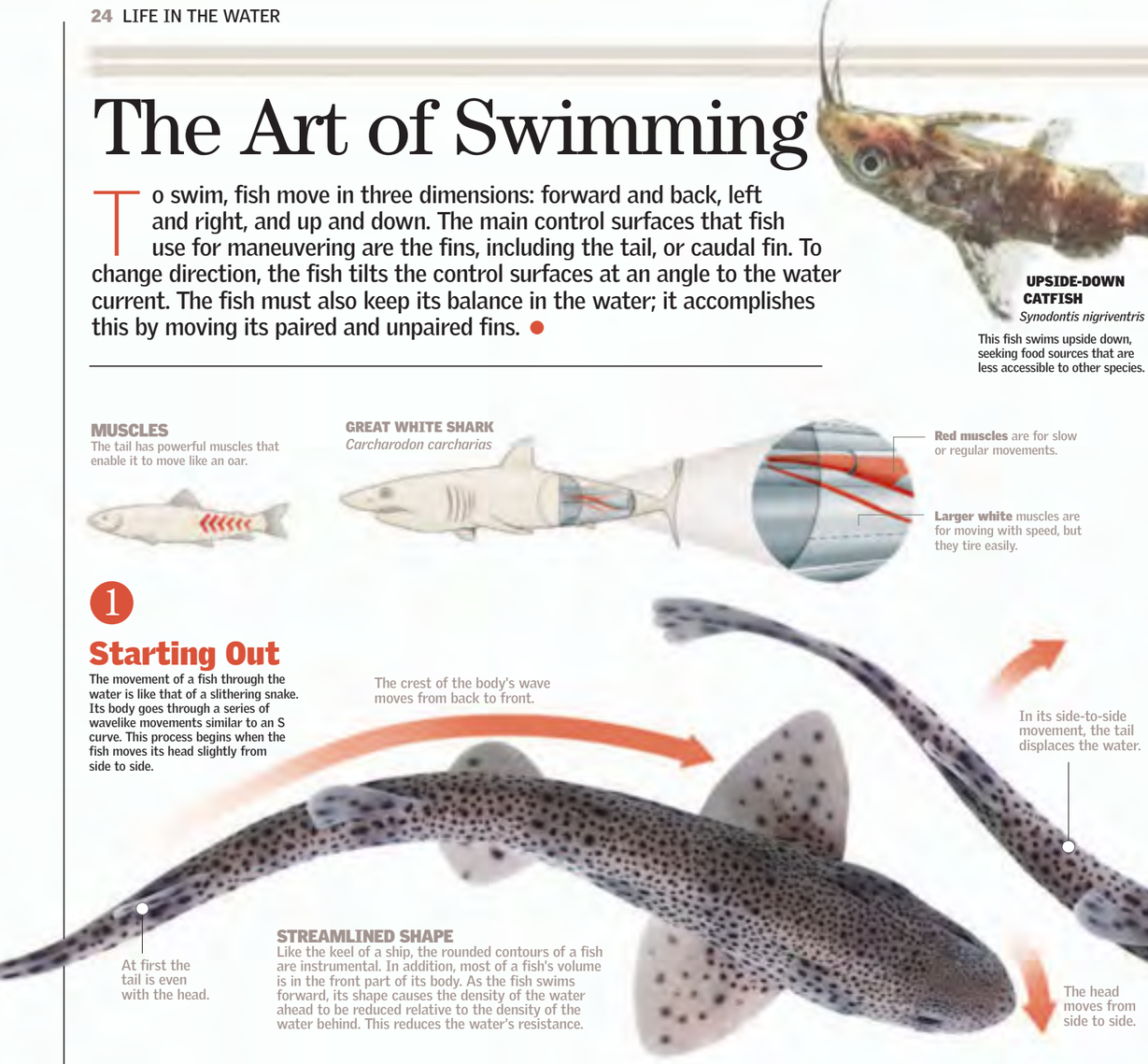
The crest of the body's wave moves from back to front.

In its side-to-side movement, the tail displaces the water.

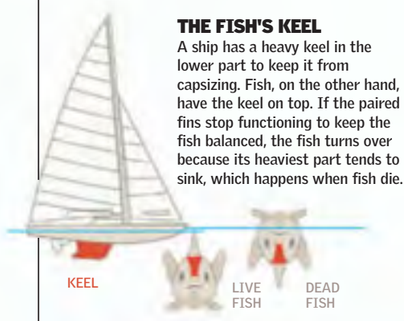
At first the tail is even with the head.

The head moves from side to side.

STREAMLINED SHAPE
Like the keel of a ship, the rounded contours of a fish are instrumental. In addition, most of a fish's volume is in the front part of its body. As the fish swims forward, its shape causes the density of the water ahead to be reduced relative to the density of the water behind. This reduces the water's resistance.



THE FISH'S KEEL
A ship has a heavy keel in the lower part to keep it from capsizing. Fish, on the other hand, have the keel on top. If the paired fins stop functioning to keep the fish balanced, the fish turns over because its heaviest part tends to sink, which happens when fish die.



THE FASTEST

SAILFISH
Istiophorus platypterus

The powerful **caudal fin** displaces large amounts of water.

The unfurled **dorsal fin** can be up to 150 percent of the width of the fish's body.

Its long **upper jaw** enables it to slice through the water, aiding this fish's hydrodynamics.

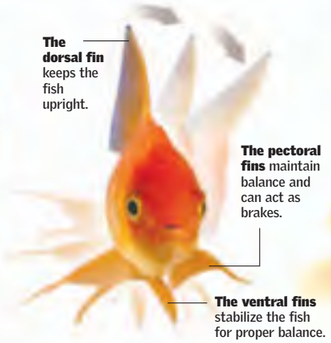
70 miles per hour (109 km/h)
The maximum swimming speed it attains

Forward Motion

results from the synchronized S-curve movement of the muscles surrounding the spinal column. These muscles usually make alternating lateral motions. Fish with large pectoral fins use them like oars for propulsion.

The oarlike movement of **the tail** is the main force used for forward motion.

Balance



The dorsal fin keeps the fish upright.

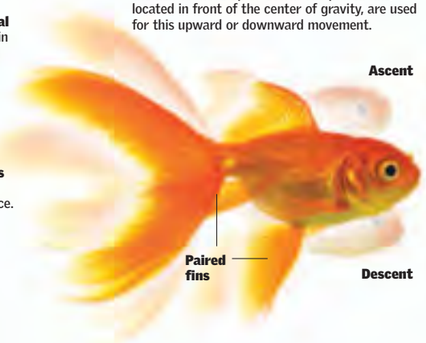
The pectoral fins maintain balance and can act as brakes.

The ventral fins stabilize the fish for proper balance.

When the fish is moving slowly or is still in the water, the fins can be seen making small movements to keep the body in balance.

Upward and Downward

The angle of the fins relative to the body allows the fish to move up or down. The paired fins, located in front of the center of gravity, are used for this upward or downward movement.



Ascent

Descent

Paired fins

2 Forceful Stroke

Muscles on both sides of the spinal column, especially the tail muscles, contract in an alternating pattern. These contractions power the wavelike movement that propels the fish forward. The crest of the wave reaches the pelvic and dorsal fins.

When the crest reaches the area between the two dorsal fins, the tail fin begins its push to the right.

The crest of the wave passes to the first dorsal fins.

The resulting impulse moves the fish forward.

3 Complete Cycle

When the tail moves back toward the other side and reaches the far right, the head will once again turn to the right to begin a new cycle.

1 second
The amount of time it takes for this shark to complete one swimming cycle

CAT SHARK
Scyliorhinus sp.

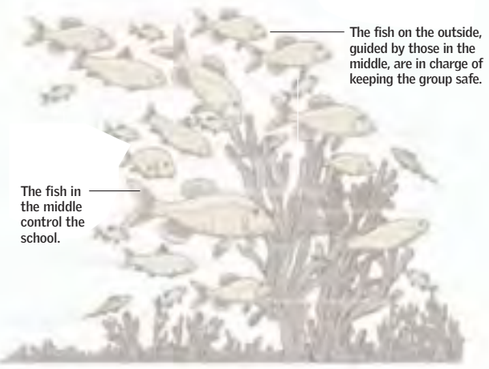
Swimming in Groups

Only bony fish can swim in highly coordinated groups. Schools of fish include thousands of individuals that move harmoniously as if they were a single fish. To coordinate their motion they use their sight, hearing, and lateral line senses. Swimming in groups has its advantages: it is harder to be caught by a predator, and it is easier to find companions or food.

School

A group of fish, usually of the same species, that swim together in a coordinated manner and with specific individual roles

1 cubic mile (4 cu km)
The area that can be taken up by a school of herring



The fish on the outside, guided by those in the middle, are in charge of keeping the group safe.

The fish in the middle control the school.

Wonders of Color

Fish use color to communicate with others of their species. They also use color in mating rituals and even to hide from their prey. A young emperor angelfish has blue and white spirals, but it develops its own appearance when it reaches maturity. This helps it to find a mate and define its territory. Today science is discovering how fish perceive differences of color and what sort of messages the colors convey. ●

SIAMESE FIGHTING FISH
Betta splendens

One of the most popular freshwater species. Only the males exhibit a wide variety of colors—red, green, blue, and purple—which they obviously use as a form of seduction.

EMPEROR ANGELFISH
Pomacanthus imperator

This fish comes in various sizes and colors. It also changes shades as it matures. Its white stripes on a blue background form concentric rings, and they grow just enough to give the adult fish magnificent horizontal yellow stripes.

OCELLARIS CLOWNFISH
Amphiprion ocellaris

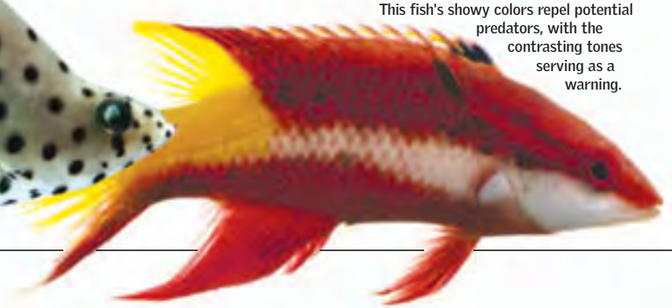
This fish has an orange body with two white bands. It lives in coral reefs from Sri Lanka to the Philippines and north of Australia.

PERCULA CLOWNFISH
Amphiprion percula

The clownfish is known for its intense red, orange, and white colors. It lives among anemones, a predator species that affords it protection from possible attackers.

HUMPBACK GROUPER
Cromileptes altivelis

This fish is found in southeast Asia, and its meat is considered a delicacy by gourmets. It lives in caves as a means of defense from predators.



WRASSE
Bodianus sp.

This fish's showy colors repel potential predators, with the contrasting tones serving as a warning.

CLOWN TRIGGERFISH
Balistoides conspicillum

Half of its body is black with large white spots, and the other half is nearly all black, with a group of strange black shapes with a yellow border. Its bright orange lips look like those of a clown.

GOLDFISH
Carassius auratus

This adaptable fish is the most popular for aquariums. Its highly developed sense of smell is important in its search for mates and food.

WHITETAIL DAMSELFISH
Dascyllus aruanus

With its white body and three thick black stripes, this fish swims among rocks and coral, blending in with its environment.

HARLEQUIN TUSKFISH
Choerodon fasciatus

One of the most brightly colored species of fish in the tropical seas, this fish is endangered by its popularity with aquarium aficionados.

MANDARIN DRAGONET
Synchiropus splendidus

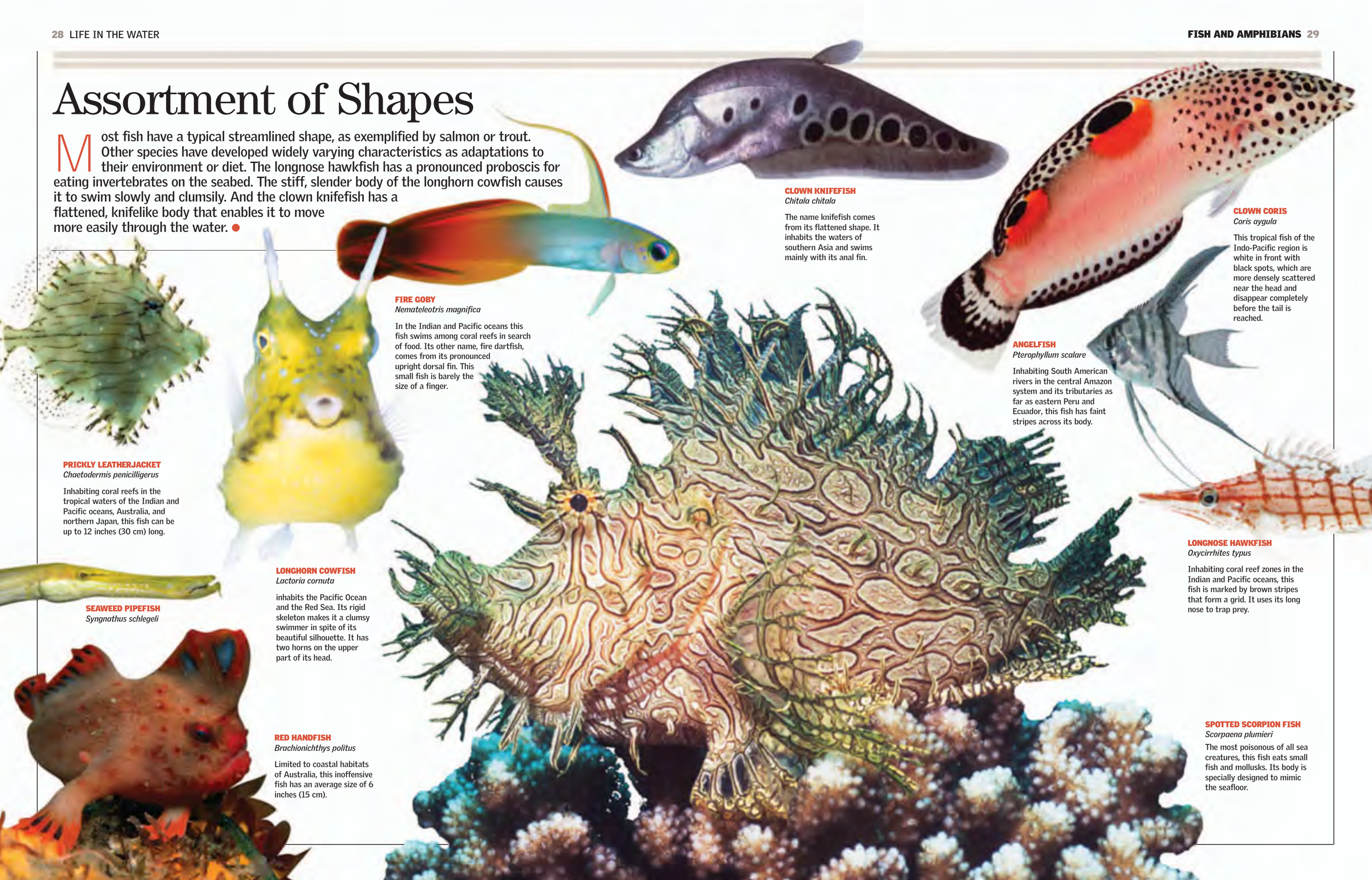
Covered with psychedelic swirls in green, blue, and yellow, this is one of the most beautiful fish on the planet. This small species lives hidden among the rocks of coral reefs.

THREADFIN BUTTERFLY FISH
Chaetodon auriga

A dark band covers each eye, and a black eye-shaped spot on its tail fools predators by making them believe the fish is bigger than it really is.

Assortment of Shapes

Most fish have a typical streamlined shape, as exemplified by salmon or trout. Other species have developed widely varying characteristics as adaptations to their environment or diet. The longnose hawkfish has a pronounced proboscis for eating invertebrates on the seabed. The stiff, slender body of the longhorn cowfish causes it to swim slowly and clumsily. And the clown knifefish has a flattened, knifelike body that enables it to move more easily through the water. ●



PRICKLY LEATHERJACKET
Chaetodermis penicilligerus

Inhabiting coral reefs in the tropical waters of the Indian and Pacific oceans, Australia, and northern Japan, this fish can be up to 12 inches (30 cm) long.

FIRE GOBY
Nemateleotris magnifica

In the Indian and Pacific oceans this fish swims among coral reefs in search of food. Its other name, fire dartfish, comes from its pronounced upright dorsal fin. This small fish is barely the size of a finger.

CLOWN KNIFEFISH
Chitala chitala

The name knifefish comes from its flattened shape. It inhabits the waters of southern Asia and swims mainly with its anal fin.

CLOWN CORIS
Coris aygula

This tropical fish of the Indo-Pacific region is white in front with black spots, which are more densely scattered near the head and disappear completely before the tail is reached.

ANGELFISH
Pterophyllum scalare

Inhabiting South American rivers in the central Amazon system and its tributaries as far as eastern Peru and Ecuador, this fish has faint stripes across its body.

LONGNOSE HAWKFISH
Oxycirrhites typus

Inhabiting coral reef zones in the Indian and Pacific oceans, this fish is marked by brown stripes that form a grid. It uses its long nose to trap prey.

SEAWEED PIPEFISH
Syngnathus schlegeli

LONGHORN COWFISH
Lactoria cornuta

inhabits the Pacific Ocean and the Red Sea. Its rigid skeleton makes it a clumsy swimmer in spite of its beautiful silhouette. It has two horns on the upper part of its head.

RED HANDFISH
Brachionichthys politus

Limited to coastal habitats of Australia, this inoffensive fish has an average size of 6 inches (15 cm).

SPOTTED SCORPION FISH
Scorpaena plumieri

The most poisonous of all sea creatures, this fish eats small fish and mollusks. Its body is specially designed to mimic the seafloor.

You Are What You Eat

Most fish feed in their natural environment, the larger fish eating the smaller ones, and the smallest sea creatures feeding on marine plants. A fish's mouth gives many clues about its feeding habits. Large, strong teeth indicate a diet of shellfish or coral; pointed teeth belong to a hunting fish; and a large mouth that is open while the fish swims is that of a filterer. Some species can also trap food that lives outside the water: trout, for example, hunt flies.

CORAL
Parrotfish feed on corals.

Predators

These are fish that feed on other species. They have teeth or fangs that help them to wound and kill their prey or to hold it fast after the attack. Predators use their sight to hunt, although some nocturnal species such as moray eels use their senses of smell and touch and those of their lateral line. All predators have highly evolved stomachs that secrete acid to digest meat, bones, and scales. Such fish have a shorter intestinal tract than herbivorous species, so digestion takes less time.

MOUTH
acts as a filter. As it swims along with its mouth open, zooplankton and small fish are trapped.

WHALE SHARK
Rhincodon typus

PIRANHA
Pygocentrus sp.

RAZOR-SHARP TEETH
Large, sharp teeth go along with a predator's diet.

Filterers

Some species have evolved to the point of being able to take from the water only those nutrients they need for feeding. They filter the nutrients out using their mouths and gills. These species include whale sharks (*Rhincodon typus*), herring (*Clupea* sp.), and Atlantic menhaden (*Brevoortia tyrannus*).

Symbiosis

is the interaction between two organisms that live in close cooperation. One type of symbiosis is parasitism, in which one organism benefits and the other is harmed. An example of a parasite is the sea lamprey (*Petromyzon marinus*), which sticks to other fish and sucks their body fluids to feed itself. Another type of symbiosis is commensalism, in which one organism benefits and the other is not harmed. An example is the remora (*Remora remora*), or suckerfish, which sticks to other fish using suction disks on the end of its head.

SUCKERS
They close their eyes, turn them, and push them downward to increase the pressure of the mouth.

REMORA
Remora remora

Plants

Life in the water is based on phytoplankton, which is eaten by zooplankton. These are in turn eaten by fish, all the way up to the large marine species.

Grazers

This group of fish eats vegetation or coral in small bites. Parrotfish (Scaridae) have a horny beak made of fused teeth. They scrape the fine layer of algae and coral that covers rocks and then crush it into powder using strong plates in the back of the throat.

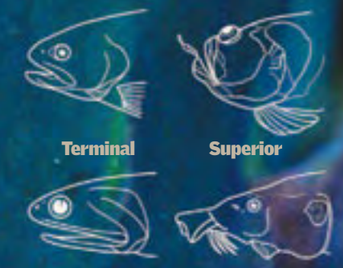
FUSED TEETH
Parrotfish have a strong beak that enables them to bite the bony skeleton of corals and eat the algae that grows on them. The beak is actually made of individual teeth, arranged in a beaklike structure.

PHARYNGEAL PLATES
After biting a clump of coral covered with algae, the pharyngeal plates, strong grinding structures in the throat, crush the hard, stony pieces.

DIFFERENCES
Carnivorous fish eat all sorts of species, even though their basic diet consists of meat. They have terminal-type mouths, muscular stomachs, and short intestinal tracts. Herbivores feed on aquatic vegetation. They have a long intestinal tract compared with other fish.

PARROTFISH
Scarus sp.

Types of Mouths



Suckers

Species that live in the depths, such as sturgeons (Acipenseridae) and suckerfish (Catostomidae), spend their days sucking the mud on the seafloor. When they are cut open, large amounts of mud or sand are found in the stomach and intestines. Digestive mechanisms process all this material and absorb only what is needed.

THE VACUUM
Sucking fish use their mouths like a large vacuum cleaner to hunt their prey.

BARBELS
The sturgeon has a prominent snout. In its mouth it has four sensitive barbels.

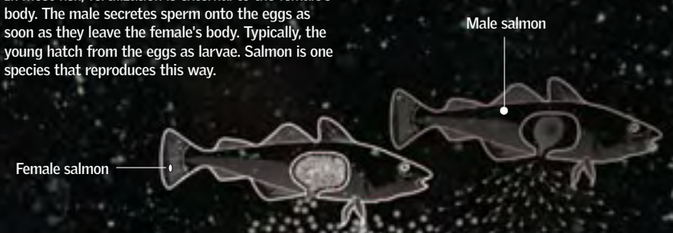
STURGEON
Acipenser sp.

Life Cycle

In an underwater environment, animals can simply secrete their sex cells into the water. But for fertilization to be effective, the male and the female must synchronize their activities. Many species, such as the salmon, travel great distances to meet with potential mates. Upon meeting a mate they release their sex cells. The time and place are important because the survival of the eggs depends on the water temperature. Parent-child relations are extremely varied, from complete neglect of the eggs once laid to constant watchfulness and protection of the young.

External Fertilization

In most fish, fertilization is external to the female's body. The male secretes sperm onto the eggs as soon as they leave the female's body. Typically, the young hatch from the eggs as larvae. Salmon is one species that reproduces this way.

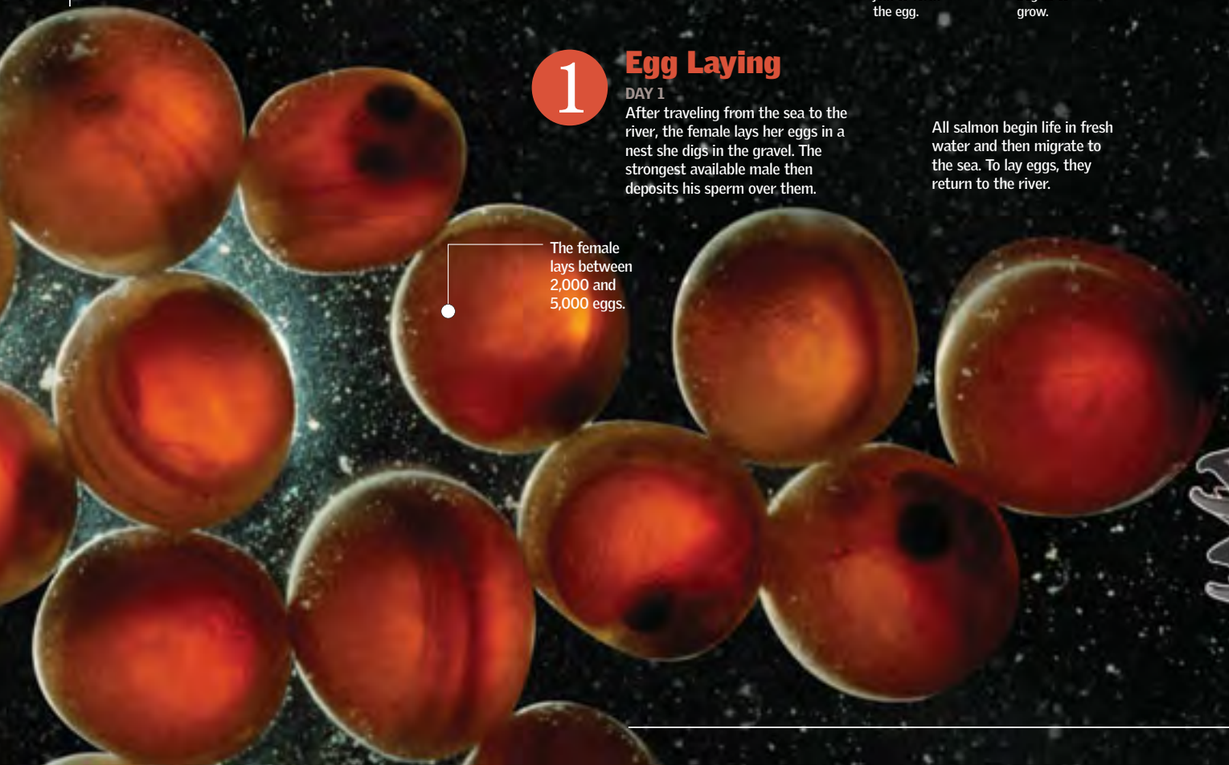


1 Egg Laying

DAY 1

After traveling from the sea to the river, the female lays her eggs in a nest she digs in the gravel. The strongest available male then deposits his sperm over them.

All salmon begin life in fresh water and then migrate to the sea. To lay eggs, they return to the river.



2 HATCHING

90 AND 120 DAYS

The period of time needed for the eggs to hatch

A The ovule and the sperm join to form the egg.

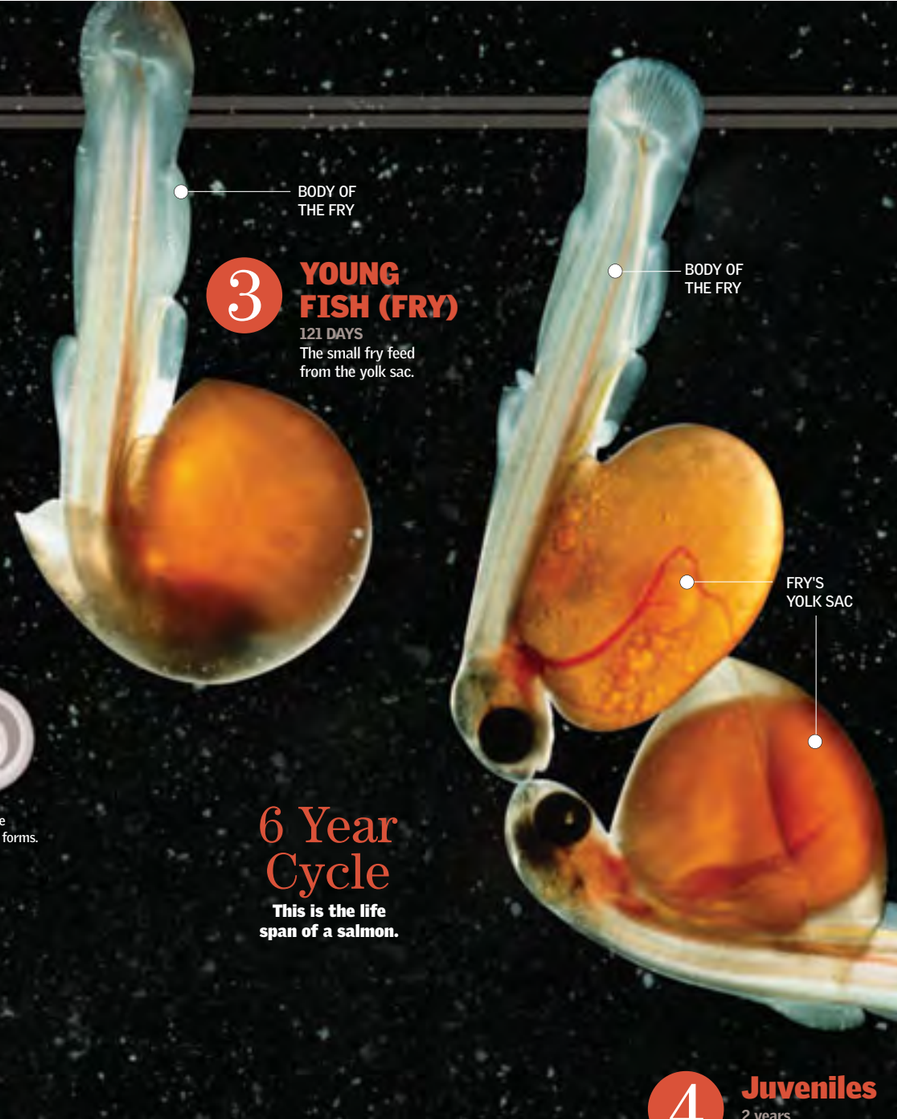
B The small living being begins to grow.

C Then the embryo forms.

3 YOUNG FISH (FRY)

121 DAYS

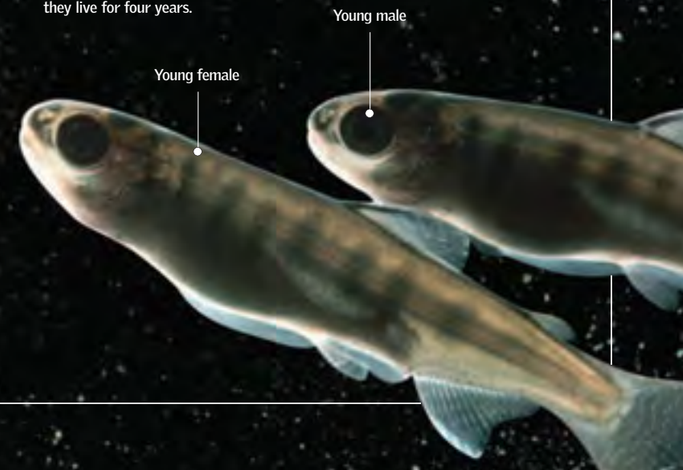
The small fry feed from the yolk sac.



4 Juveniles

2 years

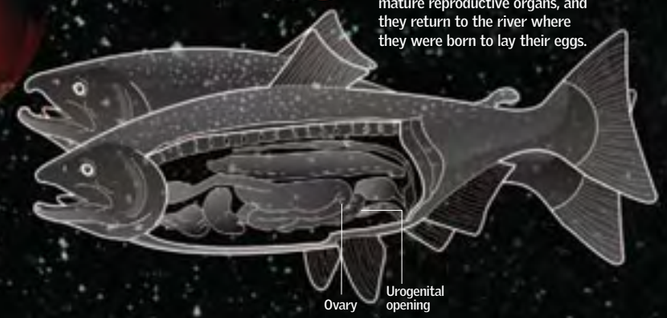
Salmon fry grow until they become small juvenile salmon. They migrate to the sea, where they live for four years.



5 Adults

6 years

The adult salmon have fully mature reproductive organs, and they return to the river where they were born to lay their eggs.



6 Year Cycle

This is the life span of a salmon.

Parents

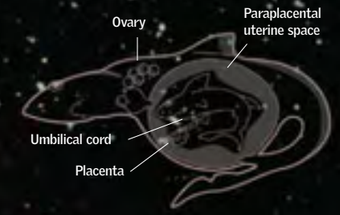
The yellow-headed jawfish, *Opisthognathus aurifrons*, incubates its eggs inside its mouth.

Mouth Incubation

The gestation of some fish species takes place inside the parents' mouths. They incubate the eggs inside their mouths and then spit them out into the burrow. Once the eggs hatch, the parents protect their young by sheltering them again inside their mouths.

Internal Fertilization

Viviparous fish give birth to their young in the form of developed juveniles. Fertilization is internal, carried out by a male organ called the gonopod, which is a modified fin.



Matters of Life and Death

To survive, most fish need adaptations to enable them to flee from their predators or to find food. The European plaice can lie on the ocean floor with its flat body. Its ivory color makes it almost invisible. The flying fish, on the other hand, developed pectoral fins to lift itself up over the surface of the water and flee its enemies.

European Plaice

The European plaice (*Pleuronectes platessa*) is a flat fish with a shape especially designed to allow it to remain motionless on the seafloor. It also provides an example of mimesis. Its two sides are very different. The top side is pigmented with small red spots that camouflage the fish on the seafloor, where it uses its fins to cover itself with sand to hide from predators.

MOUTH
The European plaice's entire body undergoes metamorphosis from its larval state to adulthood. The mouth, however, remains the same.

EUROPEAN PLAICE
Pleuronectes platessa

VENTRAL SIDE
remains an ivory color, devoid of pigmentation. This side rests on the ocean floor.

EYES
Both are located on the right side.

SPOTS
are useful for camouflage in the sand and for hiding from its predators.

GILLS
The European plaice breathes through its gills.

OPERCULUM
is the bone that supports the gill structure.

FIN
The dorsal, anal, and caudal fins form a continuous line around the body.

CAUDAL FIN
Thin, barely used for swimming.

Transformation

At birth, the European plaice does not have a flat form but looks like a normal fish. It eats near the surface and swims using its swim bladder. As time goes by, its body becomes flat. The swim bladder dries up, and the fish sinks to the bottom of the sea.

1 5 days
0.14 inch (3.5 mm)
The vertebrae begin to form.
One eye on each side

2 10 days
0.15 inch (4 mm)
The fold of the fin is forming, and the mouth is already open.

3 22 days
0.31 inch (8 mm)
The cleft of the tail develops.
The left eye moves to the top of the head.

4 45 days
0.43 inch (11 mm)
The pigment cells join to form dark spots.
It no longer looks to the right, but upward.

45 days
is the amount of time the European plaice takes to become a flat fish from a typical streamlined larva.

Flying Fish

Exocoetidae, or flying fish, are a family of ocean fish that includes 52 species grouped in eight genera. They are found in all the oceans, especially in warm tropical and subtropical waters. Their most surprising characteristic is their unusually large pectoral fins, which give them the ability to fly and glide for short distances.

1 ESCAPE
When a predator appears, the flying fish propels itself out of the water.

2 TAKEOFF
The fish comes to the surface and elevates itself as high as it can, skipping over the water.

3 GLIDING
The average gliding distance is 160 feet (50 m), but they can glide as far as 660 feet (200 m).

They reach heights of up to **19 feet (6 m)**.

These fish cover distances of up to **160 feet (50 m)** in the air.

Flying fish measure from **7 to 18 inches (18 to 45 cm)** long.

ANATOMY
This fish slides over the water with its hardened fins, and it can reach speeds up to 40 miles per hour (65 km/h) for as long as 30 seconds.

This fish has highly developed pectoral and pelvic fins.

FLYING FISH
Exocoetus volitans

Scorpion Fish

Found in the reefs of the Gulf of Mexico, *Scorpaena plumieri*, known commonly as the scorpion fish, has a brown, spotted body with many appendages that look like moss between its mouth and its eyes. This fish is hard to see because its texture and color help it blend easily into the seafloor. Its dorsal fins have a powerful venom, which causes intense pain.

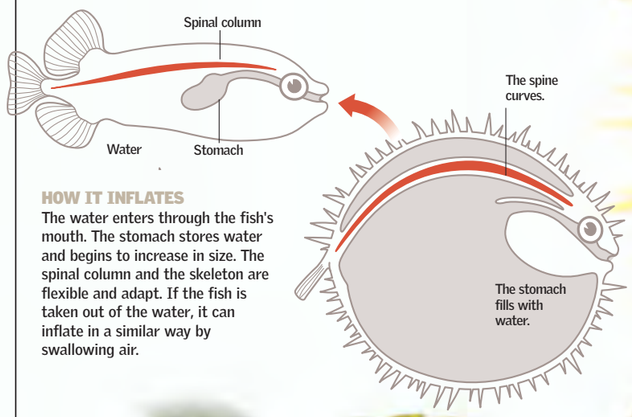
SCORPION FISH
Scorpaena plumieri

The Best Disguise

To face their enemies, fish have developed a number of strategies to enable them to survive. Some of these are escaping, hiding in the ocean bed, or stirring up sand to avoid being seen. Other species have poison, and some can inflate and raise barbs or spines to discourage predators. In the oceans' depths are fish that have luminous organs that blind the enemy. ●

Spot-Fin Porcupine Fish

Like its relative the globefish, this fish swallows water when it feels threatened, swelling up to three times its normal size. This makes it very difficult to fit inside the mouth of a predator. This fish has another defense mechanism: its modified scales act as barbs. When the fish's size increases, the scales extend perpendicularly from the skin.



HOW IT INFLATES

The water enters through the fish's mouth. The stomach stores water and begins to increase in size. The spinal column and the skeleton are flexible and adapt. If the fish is taken out of the water, it can inflate in a similar way by swallowing air.

At Rest

The scales of the porcupine fish lie flat against its body, and its appearance is no different from that of any other bony fish. When it deflates after an attack, it returns to its original state.

Self-Defense

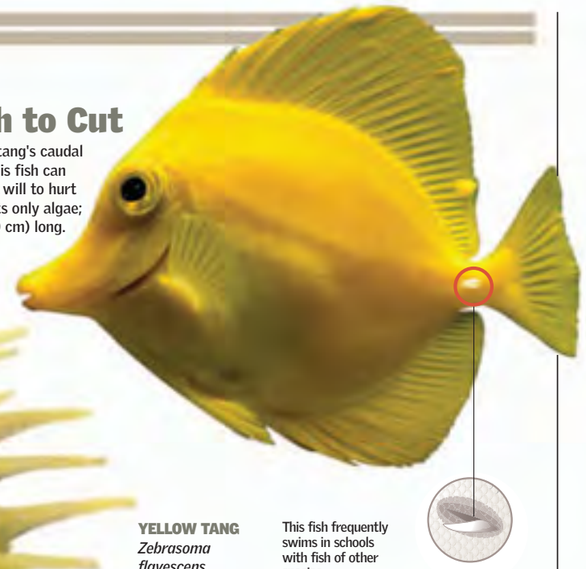
Inflated porcupine fish can reach a diameter of up to 35 inches (90 cm). This makes swallowing them impossible for medium-size predators, which are frightened simply by the porcupine fish's appearance.

SPOT-FIN PORCUPINE FISH
Diodon hystrix

STIFF SPINES
Modified scales, hard and resistant, are found all over its body, except for the tail. When these scales are extended, it is almost impossible for a predator to bite or swallow this fish.

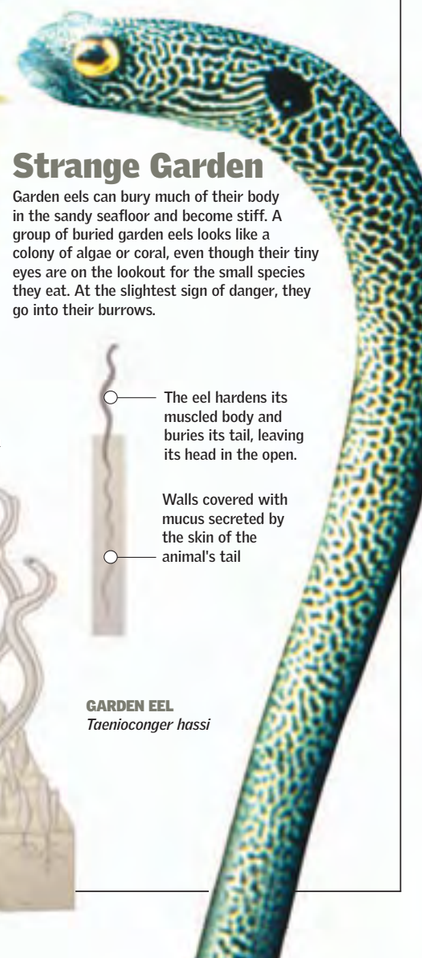
Sharp Enough to Cut

The sharp blades of the yellow tang's caudal appendage look like scalpels. This fish can retract and extend its blades at will to hurt potential attackers. The fish eats only algae; it measures some 20 inches (50 cm) long.



YELLOW TANG
Zebrasoma flavescens

This fish frequently swims in schools with fish of other species.



Strange Garden

Garden eels can bury much of their body in the sandy seafloor and become stiff. A group of buried garden eels looks like a colony of algae or coral, even though their tiny eyes are on the lookout for the small species they eat. At the slightest sign of danger, they go into their burrows.

GARDEN EEL
Taenioconger hassi

Diversity

SHARK
To locate its prey, the shark uses several of its senses-smell and hearing over long distances and sight at short range.

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The ocean depths are inhabited by many types of fish. Some are harmless, but others, such as the scorpion fish, are among the most poisonous creatures in the world. The most feared fish is the great white shark, a true underwater predatory machine—though it seldom attacks humans. In this chapter we will also tell you about the odyssey of many salmon and trout species, which can travel thousands of miles from their ocean home to lay their eggs in the rivers or lakes where they were hatched. The journey lasts from two to three months, and it involves many dangers. It requires so much energy that, after laying their eggs, many females die. ●

Long and Flexible

The seahorse is a small ocean fish that belongs to the same family as pipefish and sea dragons (Syngnathidae). Its name comes from its horselike head. In fact, no other fish genus has its head at a right angle to the rest of its body. Because it cannot use speed to escape from its predators, the seahorse has the ability to change color to blend in with its environment. The reproduction process of these fish is also very unique. The male has an incubating pouch in which the female deposits the fertilized eggs.

BLACK-STRIPED PIPEFISH
Syngnathus abaster

One of the slowest fish in the sea, the black-striped pipefish moves by means of slight undulations of its pectoral fins, which can vibrate up to 35 times per second.

Classification

Thirty-two species of seahorse have been identified worldwide. Classifying them is at times complicated because individuals of the same species can change color and develop long filaments of skin. The size of adult seahorses varies enormously, from the tiny *Hippocampus minotaur*—a species discovered in Australia that never grows beyond 0.7 inch (1.8 cm) long—to the enormous *Hippocampus ingens*, a species in the Pacific that reaches over 12 inches (30 cm) long. It has no pelvic or caudal fins, but it does have a tiny anal fin.

WEEDY SEA DRAGON
Phyllopteryx taeniolatus

Its shape is typical of this family, although its tail is not suitable for grasping, like those of seahorses are, and it has a more elongated profile. Its body is covered with seaweed.

SEAWEED
The fish lets it stick to its body so that it can escape detection.

Movement

The body of a seahorse is crammed into an armor of large, rectangular bony plates. They swim very differently than other fish. Adopting an upright position, they use their dorsal fin for propulsion. They do not have an anal fin, but rather a long tail that rolls into a spiral. They use it to hold onto underwater plants.

ROLLED UP
The tail rolls up into a curl.

GRASPING TAIL
With their long tails, seahorses can cling to plants on the seafloor.

HEAD

UNROLLED
The tail straightens out by unrolling.

TRUNK
The body is supported by the spinal column.

TAIL
Can be extended to a fully vertical position

Camouflage

Since they cannot use speed to escape from predators, seahorses and dragon fish use camouflage as a defense strategy. They change color to blend in with their environment, grow skin filaments shaped like seaweed, and use their heads to climb along the seaweed in which they live, swinging from one plant to another.

LINED SEAHORSE
Hippocampus erectus

Habitat	Caribbean, Indo-Pacific Ocean
Number of species	35
Size	7-12 inches (18-30 cm)

EYES
Large, for acute vision

NOSE
Pipe-shaped, giving the head a horselike shape

GILLS
Seahorses breathe through gills.

PECTORAL FIN
One on each side, for lateral movement

BONY PLATES
Its body is covered with concentric rings of bone.

DORSAL FIN
Seahorses swim upright, propelled by their dorsal fin.

35 species
of seahorses live in the Caribbean, the Pacific Ocean, and the Indian Ocean.

0.4 inch (1 cm)
The size of a seahorse at birth

Reproduction

The male has an incubating pouch in which the female deposits her eggs. The sac closes, and the embryos develop, nourished by the male. He later expels the young, now mature and independent, through a series of contractions.

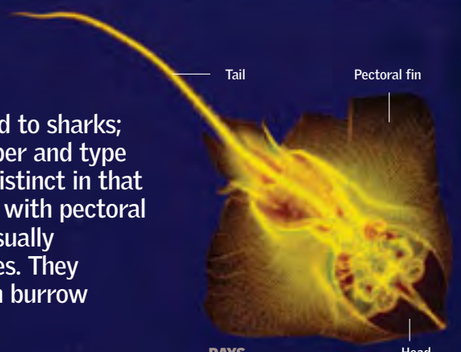
1 During the mating season the female lays some 200 eggs in the male's pouch using her egg-depositing organ. There the eggs are fertilized. When the time for birth arrives, the male clings to seaweed with his tail.

2 The male bends his body backward and forward, as if having contractions. The sac's opening widens, and the birthing process begins. Soon the young begin to appear.

3 As the male's belly contracts, the young seahorses are gradually born. Each one is 0.4 inch (1 cm) long. They begin to feed on phytoplankton right away. The birthing process can last two days, after which the male is exhausted.

Elegant Contours

The Rajiformes are an order of cartilaginous fish related to sharks; they have the same skeletal structure, the same number and type of fins, and similarly shaped gill slits. Rajiformes are distinct in that their gill slits are on the underside of the body, which is flat with pectoral fins joined to the trunk in the shape of a disk. The body is usually covered with denticles, and many have a row of dorsal spikes. They have a variety of colors, with spots and blotches. They often burrow into the mud of warm seas.



RAYS
Raja sp.

BLUE-SPOTTED RIBBONTAIL RAY
Taeniura lymma

Habitat	Indian and Pacific oceans
Diet	Crustaceans
Length	Up to 6.6 feet (2 m)
Poisonous	Yes

THERE ARE ABOUT **300** SPECIES OF RAJIFORMES

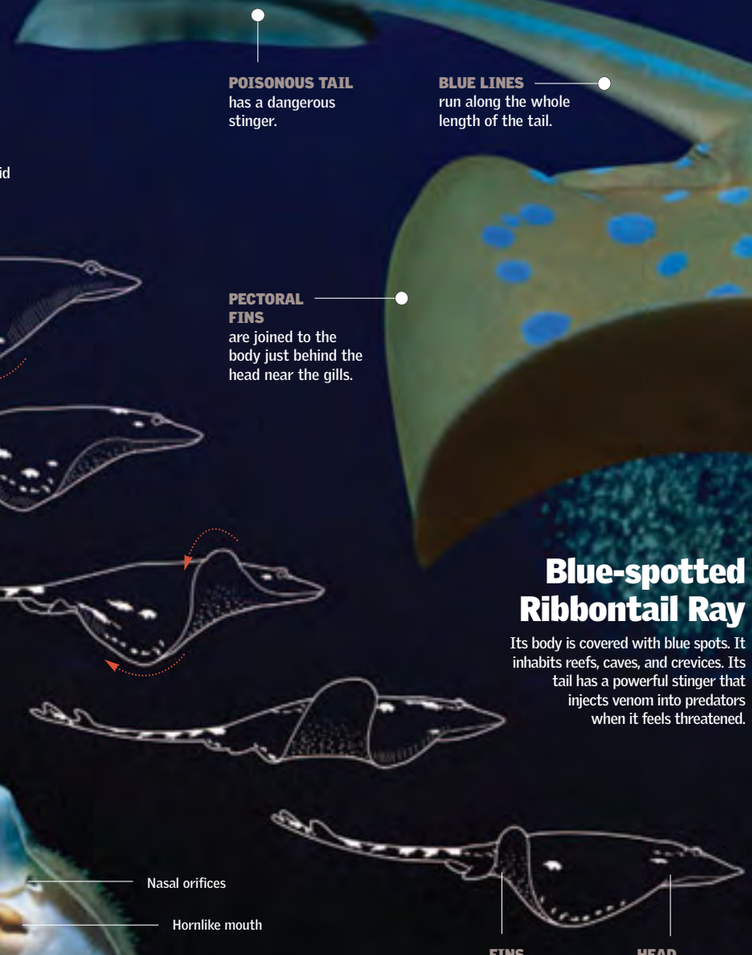
Electric Ray

Electric rays (*Torpedo* sp.) are highly active fish with electric organs on each side of the head. Each electric organ is made of numerous disk-shaped cells, connected in parallel. When all the cells fire at once, an electric current is discharged into the water at 220 volts, enough to stun the prey.

Flying Through the Water

Unlike most fish, rays have weak, slender tails that do little to power their swimming. They move with their enormous pectoral fins, which are joined to the head and have a characteristic rhomboid shape. Their movement rises and falls in an S curve, as if they were flying underwater.

12.4 miles per hour (20 km/h)



Blue-spotted Ribbontail Ray

Its body is covered with blue spots. It inhabits reefs, caves, and crevices. Its tail has a powerful stinger that injects venom into predators when it feels threatened.

Smiling Face

The ray's face is unique. It is protected by a flap on the underside of its body. Its hornlike mouth is adapted for grasping crustaceans, and the five gill slits on each side are for breathing underwater.

LITTLE SKATE
Raja erinacea

COMPARED FOR SIZE
The manta ray is the largest in the world. In spite of its large size, it is harmless, feeding only on sea plankton.

Sawfish

Fish of the order Pristiformes have long bodies with an unmistakable face, adorned with 32 pairs of denticles on each side. The females give birth to 15 to 20 young, which are born with a protective membrane over their teeth to keep from hurting the mother.

Deadly Weapon

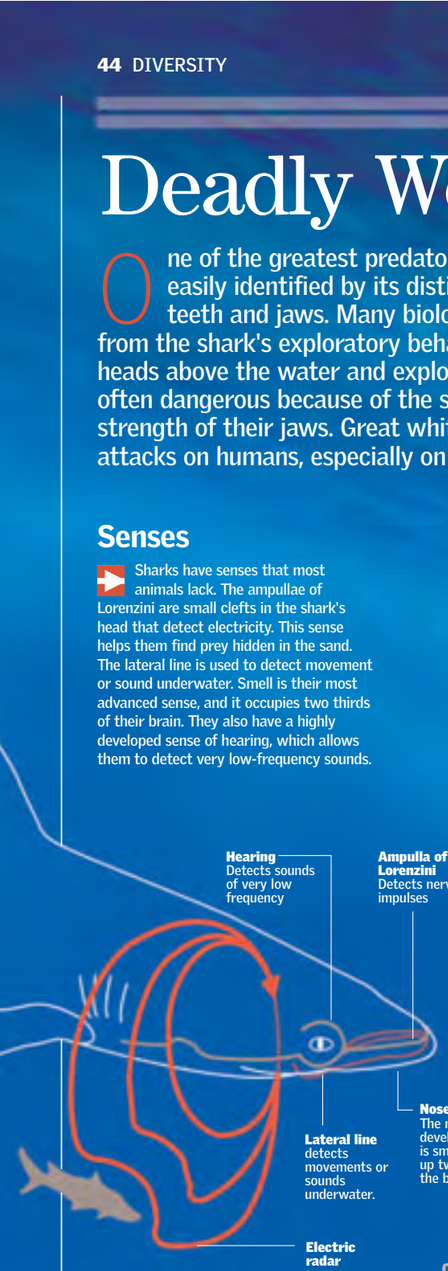
One of the greatest predators in the ocean is the great white shark, easily identified by its distinctive white coloring, black eyes, and fierce teeth and jaws. Many biologists believe that attacks on humans result from the shark's exploratory behavior, because these fish often lift their heads above the water and explore things by biting them. This activity is often dangerous because of the sharpness of the sharks' teeth and the strength of their jaws. Great white sharks are implicated in most fatal shark attacks on humans, especially on surfers and divers.

Senses

Sharks have senses that most animals lack. The ampullae of Lorenzini are small clefts in the shark's head that detect electricity. This sense helps them find prey hidden in the sand. The lateral line is used to detect movement or sound underwater. Smell is their most advanced sense, and it occupies two thirds of their brain. They also have a highly developed sense of hearing, which allows them to detect very low-frequency sounds.

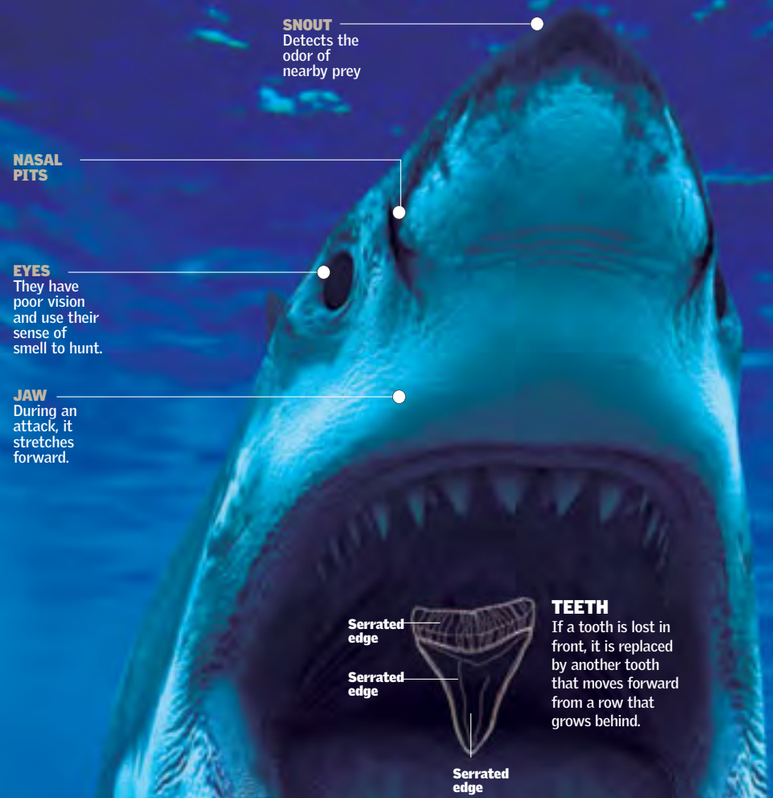
SHARK ATTACKS
1876-2004

220
ATTACKS IN 128 YEARS



GREAT WHITE SHARK
Carcharodon carcharias

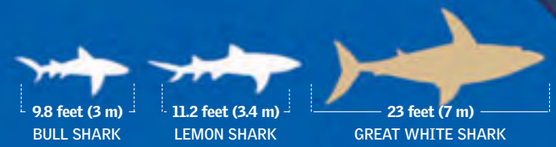
Habitat	Oceans
Weight	4,400 pounds (2,000 kg)
Length	23 feet (7 m)
Life span	30-40 years



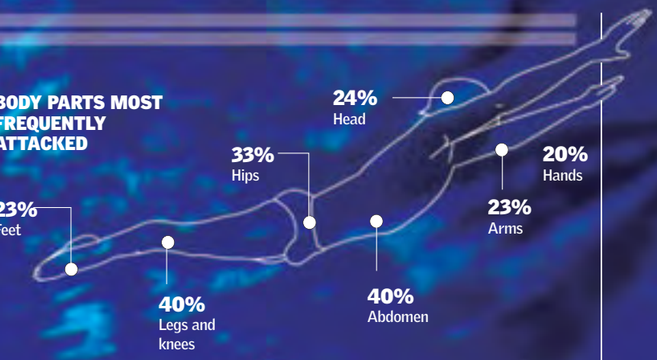
TEETH
If a tooth is lost in front, it is replaced by another tooth that moves forward from a row that grows behind.

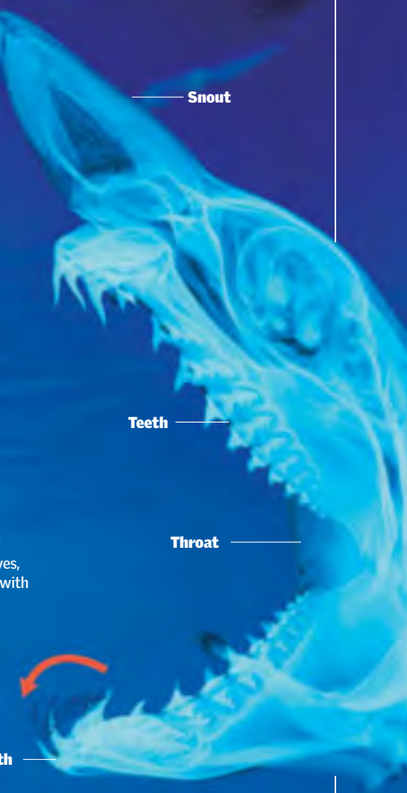
COMPARISON WITH OTHER SPECIES

The great white shark, at 23 feet (7 m) long, is one of the largest of its genus.



BODY PARTS MOST FREQUENTLY ATTACKED





1 RAISED SNOUT
The head is raised and the jaws open.

2 THE JAWS ADVANCE
The shark grabs the prey with its teeth and holds it until it is dead.

REPLACEMENT TEETH
Sharks lose thousands of teeth throughout their lives, but each one is replaced with a new tooth.

Jaw

The shark's jaws are made of cartilage instead of bone, and they are located underneath the skull. When the animal closes in on its prey, it raises its snout. The jaws slide forward, away from the skull, for a better grip. Most shark teeth have serrated edges for cutting flesh. The sharp points are for perforating, and the wide, flat surfaces are for crushing.

Time to Eat

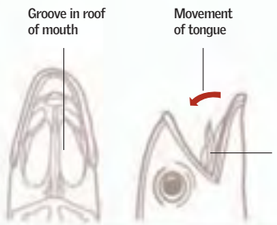
Most fish feed within their aquatic environment. Some species, however, seek their food outside the water. The best-known example is the archerfish, which shoots streams of water from its mouth to knock spiders and flies off nearby plants and into the water. The African butterfly fish eats flying insects, which it traps after a brief flight. The river hatchetfish has a similar strategy: its long pectoral fins and flattened body enable it to make great leaps.

Archerfish

Seven species of archerfish live in the tropical waters of India and southeast Asia. They hunt using an unusual technique of spitting streams of water.

Technique

The tongue presses upward against a groove in the roof of the mouth, forming a tube for emitting the stream of water.

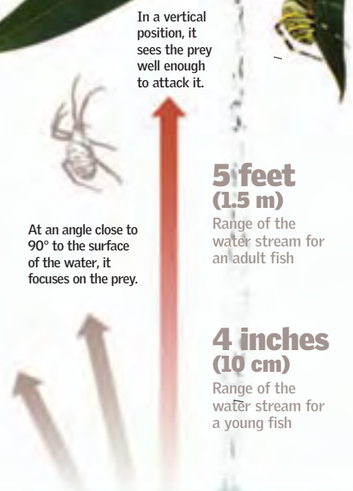


Angle of vision

Archerfish have large eyes and excellent vision for hunting.

90°

EXACT ANGLE OF VISION



5 feet (1.5 m)
Range of the water stream for an adult fish

4 inches (10 cm)
Range of the water stream for a young fish

Leap

Not only can archerfish shoot their prey, but they can also leap out of the water and make the prey fall in order to eat it.

12 inches (30 cm)

HEIGHT IT CAN REACH IN ONE JUMP

Warm
Temperature of the waters the archerfish inhabits

African Butterfly Fish

It inhabits pools and slow rivers in Africa, from Nigeria to the Republic of the Congo. The butterfly fish hunts in small groups near the shore, hiding among roots and floating plants. It uses its pectoral fins to "fly" out of the water to capture food or to escape from predators. It eats flying insects, which it traps on its short flights, and small fish.

6.6 feet (2 m)

MAXIMUM LENGTH OF A LEAP

Strategy

The carnivorous archerfish has developed a special strategy for hunting live insects, which is highly effective for hunting prey outside the water at distances of up to 5 feet (1.5 m).

A SEARCH
The archerfish looks upward in search of its prey.

B SHOT
When it finds its prey, the archerfish positions its body upright and shoots a stream of water at the target.

C AIM
If the first stream misses, the fish tries again and again.

Archerfish
Toxotes jaculatrix

Found in southeast Asia, India, and northern Australia, it lives in brackish waters with temperatures of 77-86° F (25-30° C).

2.75 inches (7 cm)

LENGTH OF THE HATCHETFISH

Hatchetfish

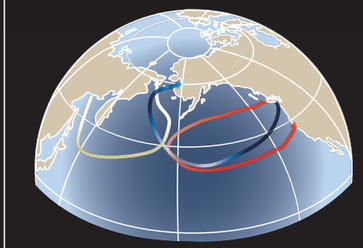
This carnivorous, freshwater fish comes from South and Central America. It swims in schools and can reach lengths of up to 2.75 inches (7 cm). It always swims very close to the surface. Its long pectoral fins and flattened body enable it to leap high out of the water.

African butterfly fish
Pantodon buchholzi

Hatchetfish
Gasteropelecus sternicla

The Journey Home

After living in the ocean for five or six years, the Pacific red salmon (*Oncorhynchus nerka*) returns to the river where it was born to reproduce. The journey lasts from two to three months, and it demands a great deal of energy. The salmon must swim against the current, climb waterfalls, and evade predators, including bears and eagles. Once the salmon reach the river, the female lays her eggs, and the male fertilizes them. Typically, the same locations in specific rivers are sought year after year. This species of salmon dies after completing the reproductive cycle, unlike the Atlantic salmon, which repeats the cycle three or four times. Once the eggs hatch, the cycle begins anew. ●



ASIA ALASKA U.S..

The Route

There are six species of salmon in the Pacific Ocean and one in the Atlantic. The red salmon (*Oncorhynchus nerka*) migrates from the Pacific Ocean to the rivers of the United States and Canada on one side and to the rivers of Alaska and eastern Asia on the other.

3 months

ESTIMATED DURATION OF THE SALMON'S JOURNEY TO THE RIVER WHERE IT WAS BORN

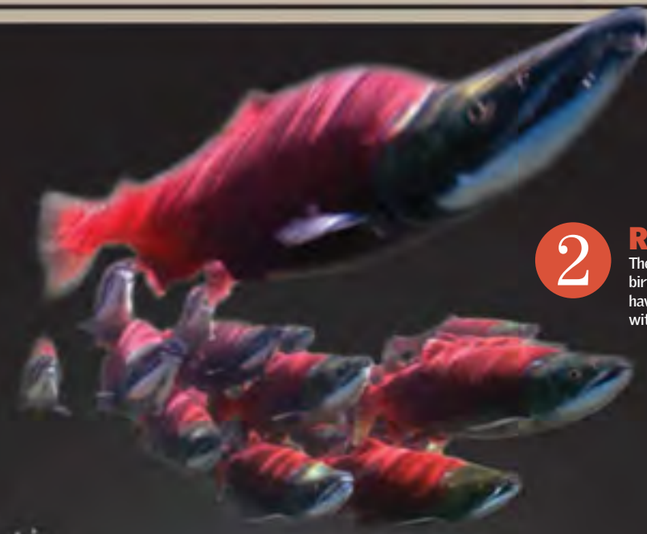
1 Strenuous Race

Salmon swim upstream from the ocean to the river. On the way many fall prey to bears.

Neither waterfalls nor strong currents can stop salmon in their journey.

2 Red River

The salmon returns to its birthplace to spawn. Males have intense coloration with a green head.



Seen from above, salmon appear as a large red spot.

Survival

Of the more than 7,500 eggs that two females can lay, only two hatched fish will remain at the end of the life cycle of two years. Many eggs die before hatching, and after hatching, salmon fry are easy prey for other fish.

3 The Couple

While females are busy preparing nests in the sand to deposit their eggs, males compete for mates.

5,000

QUANTITY OF EGGS A FEMALE CAN LAY

6-Year Cycle

LENGTH OF TIME FROM SPAWNING TO ADULTHOOD

MOUTH
During mating season, the lower jaw of the male curves upward.

BACK
A hump develops in the dorsal section of the body.

COLOR
The blue-backed salmon turns a fiery red.

4 Spawning

The female deposits between 2,500 and 5,000 eggs in a series of nests. The male fertilizes them as they fall between the rocks.

5 Fry

Only 40 percent of the eggs laid each autumn hatch. The fry remain in the river for up to two years and then migrate to the ocean.

6 Death

Adult salmon die a few days after spawning, exhausted by the work they have done. Their bodies decompose along the river bank.

Habitat, Tastes, and Preferences

The oceans cover 70 percent of the Earth's surface. That is where life began on this planet and where the most primitive species live side by side with the most highly evolved ones. This abundance of species is due in part to the wide variety of environments found in the ocean. As one descends in depth, the water's temperature decreases, as does the amount of light. These factors determine different ecosystems, feeding regimes, and adaptation strategies among a wide variety of fish species.

Reserve of Life

Corals need warm water and lots of light. They are colonies of polyps that secrete a calcareous substance that form great reefs over the years. The resulting microhabitat harbors a great variety of species.

REEFS
form only in very shallow tropical waters.

0-650 feet
(0-200 m)

Epipelagic Zone
Algae and the animals that eat them inhabit this zone, where photosynthesis is possible because of the presence of sunlight.

490 feet
(150 m)

At this depth there is no plankton. Many species that live below this depth swim above it at night to feed.

650-3,300 feet
(200-1,000 m)

Mesopelagic Zone
Not enough light is found at this depth to allow algae to live.

2,000 feet
(600 m)

No light whatsoever reaches this depth.

BOTTOM FEEDERS
At any given depth of the ocean floor, bottom feeders can be found wallowing in the mud searching for food.

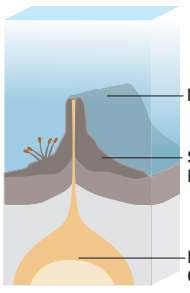
3,300-13,000 feet
(1,000-4,000 m)

Bathypelagic Zone
Species that inhabit this zone do so in complete darkness, except for those creatures that are bioluminescent, generating their own light. Temperature varies between 35° and 40° F (2° and 4° C).

Below 13,000 feet
(4,000 m)

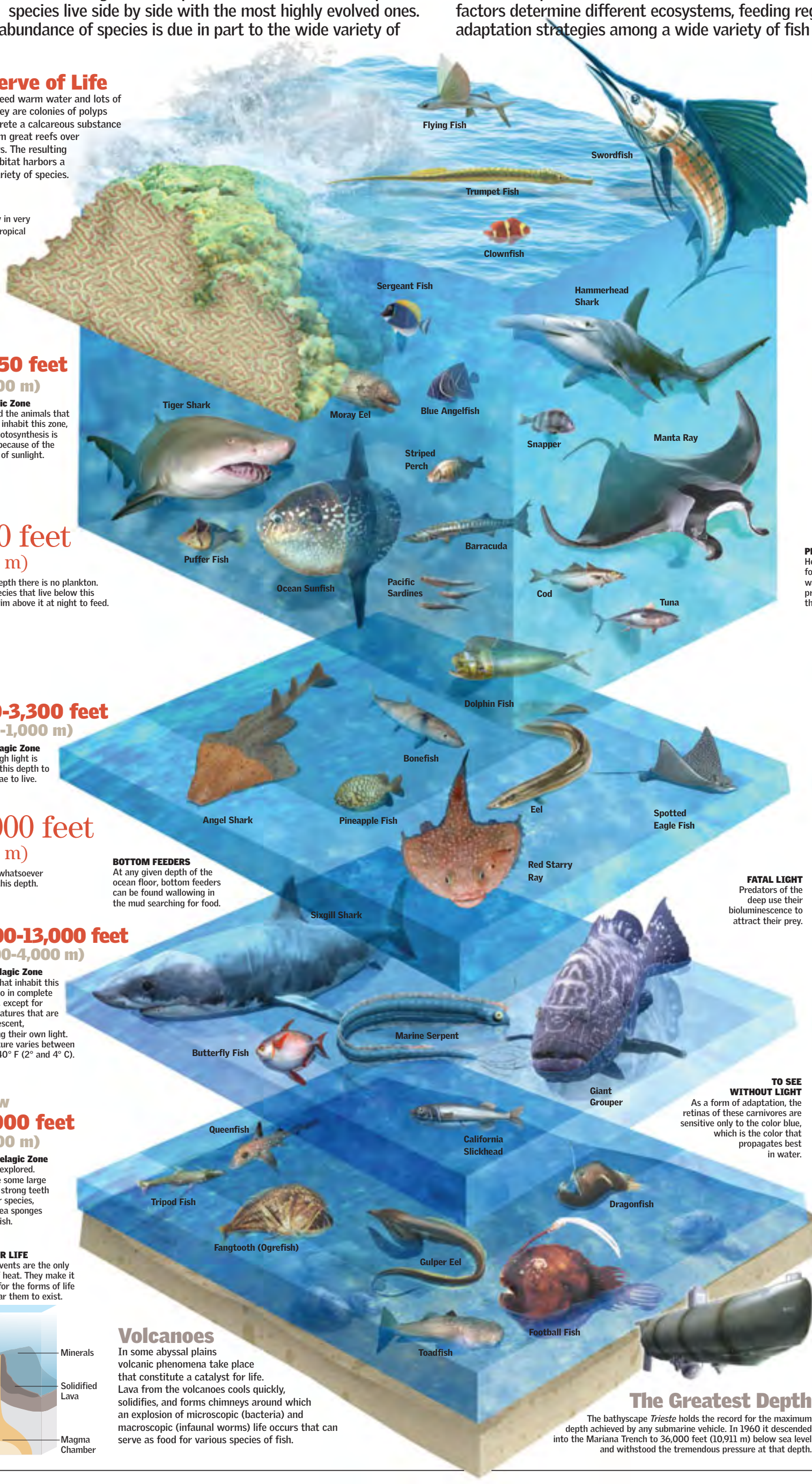
Abyssopelagic Zone
Scarcely explored. There are some large fish with strong teeth and other species, such as sea sponges and starfish.

HEAT FOR LIFE
Volcanic vents are the only source of heat. They make it possible for the forms of life found near them to exist.



Volcanoes

In some abyssal plains volcanic phenomena take place that constitute a catalyst for life. Lava from the volcanoes cools quickly, solidifies, and forms chimneys around which an explosion of microscopic (bacteria) and macroscopic (infaunal worms) life occurs that can serve as food for various species of fish.



PLANKTON
Herbivorous fish can be found only in shallow waters because of the presence of plankton there.

FATAL LIGHT
Predators of the deep use their bioluminescence to attract their prey.

TO SEE WITHOUT LIGHT
As a form of adaptation, the retinas of these carnivores are sensitive only to the color blue, which is the color that propagates best in water.

30 feet (9 m)
Divers without special equipment

50 feet (15 m)
Pearl divers

160 feet (50 m)
Scuba divers

1,150 feet (350 m)
S.P.350 saucer of Cousteau

1,300 feet (400 m)
JIM diving suit (1970)

3,000 feet (915 m)
Barton bathosphere (1960)

5,000 feet (1,525 m)
Submarine rescue vehicle

12,500 feet (3,810 m)
Deep submergence vehicle Alvin

19,800 feet (6,000 m)
MIR (Russia)

21,500 feet (6,500 m)
Shinkay (Japan)

The Greatest Depth

The bathyscape *Trieste* holds the record for the maximum depth achieved by any submarine vehicle. In 1960 it descended into the Mariana Trench to 36,000 feet (10,911 m) below sea level and withstood the tremendous pressure at that depth.

36,000 FEET (10,911 M)

650 feet (200 m)
3,300 feet (1,000 m)
13,200 feet (4,000 m)

Danger in the Water

There are poisonous fish in all the seas in the world. The toxic substances they produce are usually not meant for threatening humans but for defending themselves from larger aquatic predators. Although some species of puffer fish have poisonous flesh, in Japan they are considered a delicacy when properly prepared. ●

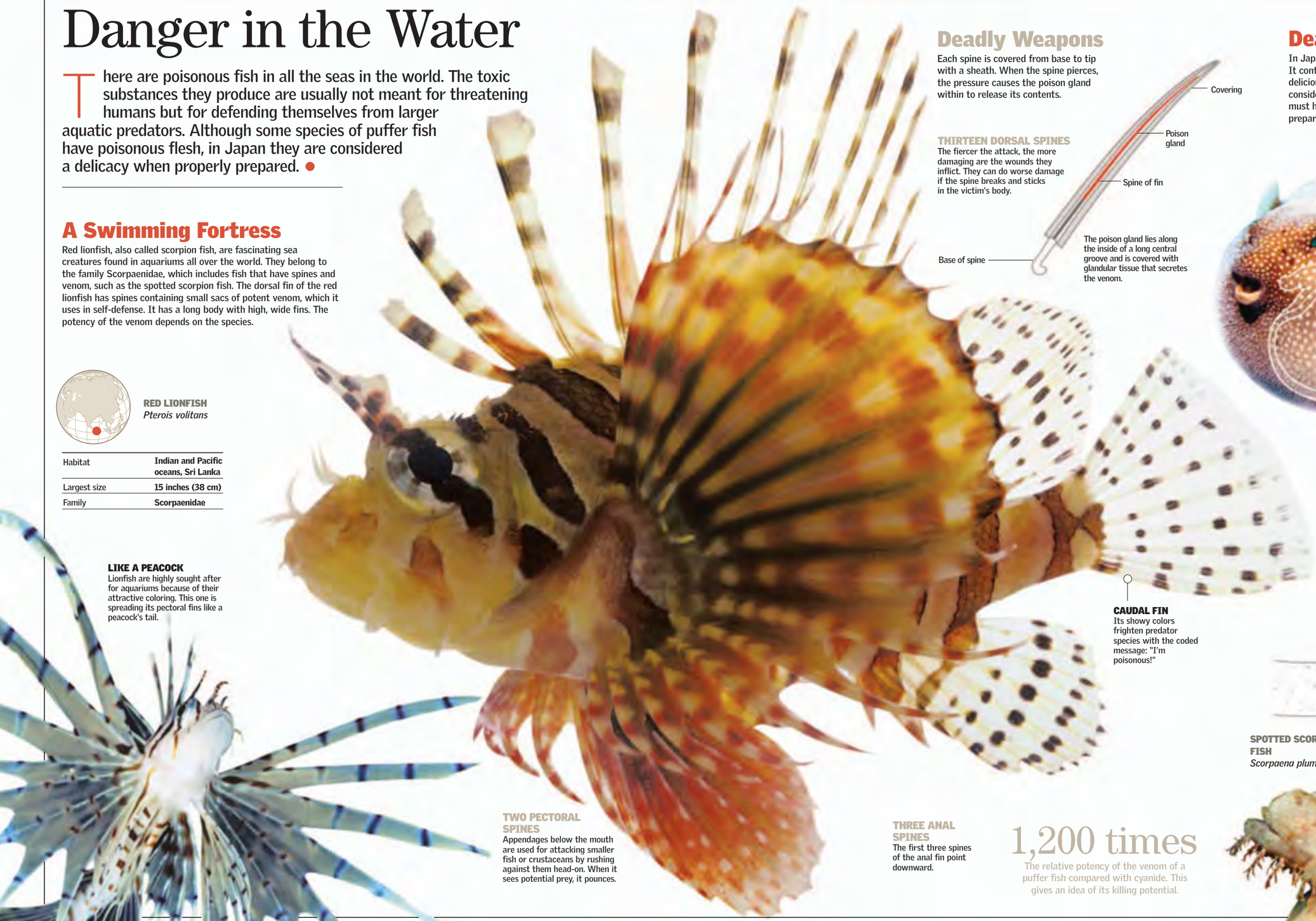
A Swimming Fortress

Red lionfish, also called scorpion fish, are fascinating sea creatures found in aquariums all over the world. They belong to the family Scorpaenidae, which includes fish that have spines and venom, such as the spotted scorpion fish. The dorsal fin of the red lionfish has spines containing small sacs of potent venom, which it uses in self-defense. It has a long body with high, wide fins. The potency of the venom depends on the species.

RED LIONFISH
Pterois volitans

Habitat	**Indian and Pacific oceans, Sri Lanka**
Largest size	**15 inches (38 cm)**
Family	**Scorpaenidae**

LIKE A PEACOCK
Lionfish are highly sought after for aquariums because of their attractive coloring. This one is spreading its pectoral fins like a peacock's tail.



TWO PECTORAL SPINES
Appendages below the mouth are used for attacking smaller fish or crustaceans by rushing against them head-on. When it sees potential prey, it pounces.

THREE ANAL SPINES
The first three spines of the anal fin point downward.

CAUDAL FIN
Its showy colors frighten predator species with the coded message: "I'm poisonous!"

Deadly Weapons

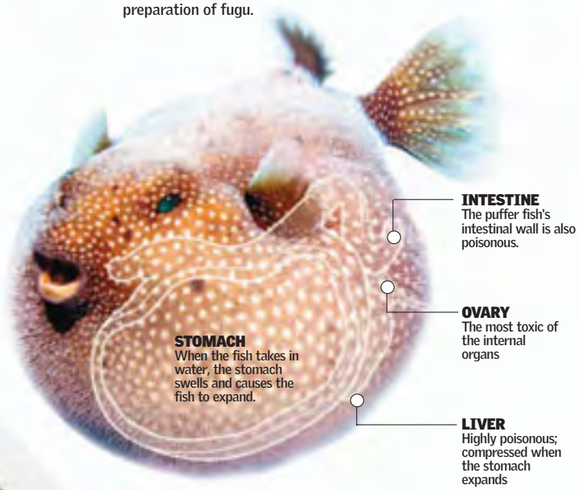
Each spine is covered from base to tip with a sheath. When the spine pierces, the pressure causes the poison gland within to release its contents.

THIRTEEN DORSAL SPINES
The fiercer the attack, the more damaging are the wounds they inflict. They can do worse damage if the spine breaks and sticks in the victim's body.

The poison gland lies along the inside of a long central groove and is covered with glandular tissue that secretes the venom.

Deadly Delicacy

In Japan the fugu, or puffer fish, is a succulent but lethal delicacy. It contains tetratoxin, a deadly poison. Nonetheless, its flesh is so delicious that Japanese gourmets, even at the risk of their lives, consider fugu the king of fish. To prepare this high-risk dish, chefs must have a certificate from a special school that teaches the preparation of fugu.



STOMACH
When the fish takes in water, the stomach swells and causes the fish to expand.

INTESTINE
The puffer fish's intestinal wall is also poisonous.

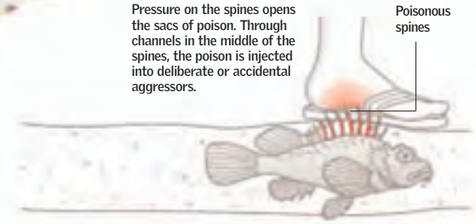
OVARY
The most toxic of the internal organs

LIVER
Highly poisonous; compressed when the stomach expands

Living Rock

Spotted scorpion fish belong to another group of the Scorpaenidae family. Buried in the sand along ocean beaches, their strong, thick spines can pierce footwear when stepped on. They can live up to four months eating only the fish that swim near their mouths.

Pressure on the spines opens the sacs of poison. Through channels in the middle of the spines, the poison is injected into deliberate or accidental aggressors.



SPOTTED SCORPION FISH
Scorpaena plumieri

1,200 times
The relative potency of the venom of a puffer fish compared with cyanide. This gives an idea of its killing potential.

Kings of Darkness

In depths below 8,200 feet (2,500 m), where barely any light penetrates, live rare species known as abyssal fish. In this environment, life is possible near hydrothermal vents in the seafloor that warm the nearby waters. In spite of this natural warmth, in many areas the temperature never rises above 36° F (2° C). At this depth fish have peculiar shapes, with large heads and strong teeth for eating other fish, since no vegetation can grow there. To attract their prey, many have "lure" organs made of photophores that shine in the darkness. They also are usually black or dark brown for purposes of camouflage.

SHARP, POINTED TEETH
It gulps down its prey after grabbing them with its enormous teeth and its strong suction force.

FANFIN SEADEVIL
Caulophryne jordani
This dark-brown fish uses the photophore organ on its head to penetrate the darkness.

LANTERN
Like most abyssal fish, it has a lure organ.

SLOANE'S VIPERFISH
Chauliodus sloani
Between 12 and 20 inches (30 and 50 cm) in stature, it is dark blue or silvery in color and lives in warm tropical waters.

EYES FOR SEEING IN DIM LIGHT

RAY OF LIGHT

TAPETUM
reflects light like a mirror. Each ray hits the retina twice, doubling its sensitivity.

RETINA
Blind to red light. It registers only blue light waves, which travel better in the water.

FILAMENTS
cover its entire body for protection.

FANGTOOTH
Anoplogaster cornuta
This fearsome hunter kills its prey by seizing it with its jaw and strong teeth.

BODY
Black, to avoid being seen by predators

GLOWING LURE
Produces light to attract prey

KILLER JAWS
In the ocean's depths, only the best hunter survives.

CHIN APPENDAGE
Produces light to attract prey

ILLUMINATED NETDEVIL
Linophryne arborifera
has a glowing lure on the end of its nose and a branching beard that also glows to attract prey. The male is smaller than the female and lives off of her like a parasite.

DIMENSIONS
Weight
10.6 ounces (300 g)
4 inches (10 cm)

TAILS AND FINS
contain luminous cells.

GLOWING LURE
gives off light to attract prey.

ATLANTIC FOOTBALL FISH
Himantolophus groenlandicus
The females can reach up to 24 inches (60 cm) long, whereas the males barely reach 1.6 inches (4 cm) long and live as parasites on their mates.

CHIN APPENDAGE
Shines in the darkness

DRAGONFISH
Bathophilus sp.
Found in most tropical regions of the world, it has photophores along both sides of its body.

LANTERN
produces bluish light, which reaches farthest underwater.

SKIN
Dark colors are likely to make it invisible to attackers.

HUMPBACK ANGLERFISH
Melanocetus johnsonii
6 inches (15 cm) long. Its small fins are insufficient to enable fast maneuvering.

FUMAROLE
Openings in the Earth's surface that discharge geothermal water and minerals. As the water cools, these minerals solidify.

36° F (2° C)
Temperature of water heated by fumaroles.

HYDROSTATIC PRESSURE
The weight of the column of water. The pressure of the water increases with depth. In the Mariana Trench (the deepest undersea trench on the planet), every square centimeter bears the weight of 1.2 tons (7.7 tons per square inch) of water.

8,200 feet (2,500 m)
Depth of water

1.3 cubic yards (1 cu m) of water = 1.1 tons (1,000 kg)

TUBE WORM TENTACLES
Tube worms have neither mouths nor digestive tracts. They feed on organic molecules formed from elements in the water by chemosynthetic bacteria that live inside the worms.

Sea Snakes

Eels (Anguilliformes), an order of ray-finned fish (Actinopterygii), are distinctive for their elongated, snakelike shape. In the past they were an important food source. There are about 600 species of true eels, including morays, congers, and snake eels. Eels come in a wide variety of colors and patterns, ranging from solid gray to mottled yellow. Their bodies lack scales and are covered with a protective mucous membrane. One of the most striking eels is the green moray, which lives in the Caribbean Sea and hides in coral reefs awaiting its prey. Although it is not poisonous, it is feared by divers because its bite can inflict grave wounds.

GREEN MORAY
Gymnothorax funebris

Habitat	Caribbean Sea
Depth	25-200 feet (8-60 m)
Weight	64 pounds (29 kg)

Weight
64 pounds
(29 kg)

8.2 feet
(2.5 m)

Green Moray

Unlike most fish, the moray has no scales. It excretes a slippery film to cover its thick, muscular body and protect itself from parasites. The moray hunts at night and detects its prey with its excellent sense of smell.

VISION
Very poor

SMELL
Highly developed. This sense is used to detect prey.

MOUTH

FINLESS
Its elongated, muscular body lacks pectoral and pelvic fins. Its long dorsal and anal fins, however, end in a short tail fin.

How It Attacks Its Prey

A Hiding place
It lives in crevices and caves in coral reefs, where it peers out, waiting to pounce on its prey.

Prey

B Attack
At night it detects its prey (fish and octopuses). It traps them with its sharp teeth, which slant backward to keep the prey from escaping.

It slashes the prey with its teeth.

C Coiling
After gulping down the animal whole, the eel forms two curls with its body to crush and flatten the prey in its digestive tract.

It crushes the prey with its body.

Upper jaw has a double row of teeth.

Lower jaw has only one row of teeth.

27 Total number of teeth

600
species of eel exist in the world.

BLUE RIBBON EEL
Rhinomuraena quaesita
inhabits the waters of the Indian and Pacific oceans and feeds on small fish. Females have a yellow dorsal fin.

Its two-colored body lacks scales.

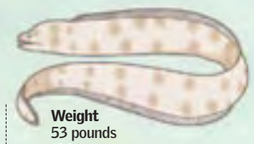
Weight
8 pounds
(3.6 kg)

40 inches
(1 m)

CONGER
Conger conger
There are 100 species of congers. This one is dark gray.

Weight
143 pounds
(65 kg)

8.9 feet
(2.7 m)



Weight
53 pounds
(24 kg)

31 inches
(80 cm)

SNOWFLAKE MORAY
Echidna nebulosa
It grows rather slowly and can take up to two years to reach adult size.

Its dark-brown and yellow body is covered with a protective mucous layer.

Out of the Water

Some species of fish can breathe and live out of the water. They include the mudskippers in southeast Asia, which can stay on muddy flats and even climb trees. To breathe, they need only their skin to stay moist, thanks to the function of certain cells in their skin. A few other species still have rudimentary lungs like those of the first aquatic animals that colonized dry land.

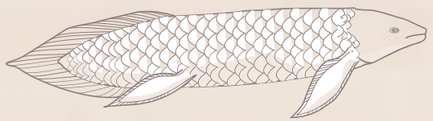
Fish with Lungs

Lungfish have rudimentary lungs that originate from a connection between the swim bladder and the esophagus. This allows the swim bladder to function using air when the fish leaves the water. Depending on the species, the fish can breathe air occasionally or even indefinitely. Many varieties of these fish have been found in fossil form all over the world, which indicates that they were very widespread during the Mesozoic Era. They were probably the first vertebrates to develop lungs. However, lungfish species are found in only three areas today, all in freshwater environments.

SOUTH AMERICAN LUNGFISH
Lepidosiren paradoxa
has a small gill apparatus and two lungs with which it breathes during the dry season..

WEST AFRICAN LUNGFISH
Protopterus annectens annectens
has fleshy fins that look like limbs and three external gills. In the dry season it secretes a substance for covering itself. It can remain in this state for up to a year.

9 months
Length of time certain lungfish can live buried in the mud



QUEENSLAND LUNGFISH
Neoceratodus forsteri
When forced to breathe air for long periods, this fish will die. It can reach up to 50 inches (1.25 m) long, weigh 22 pounds (10 kg), and live more than 65 years..

In the Mud

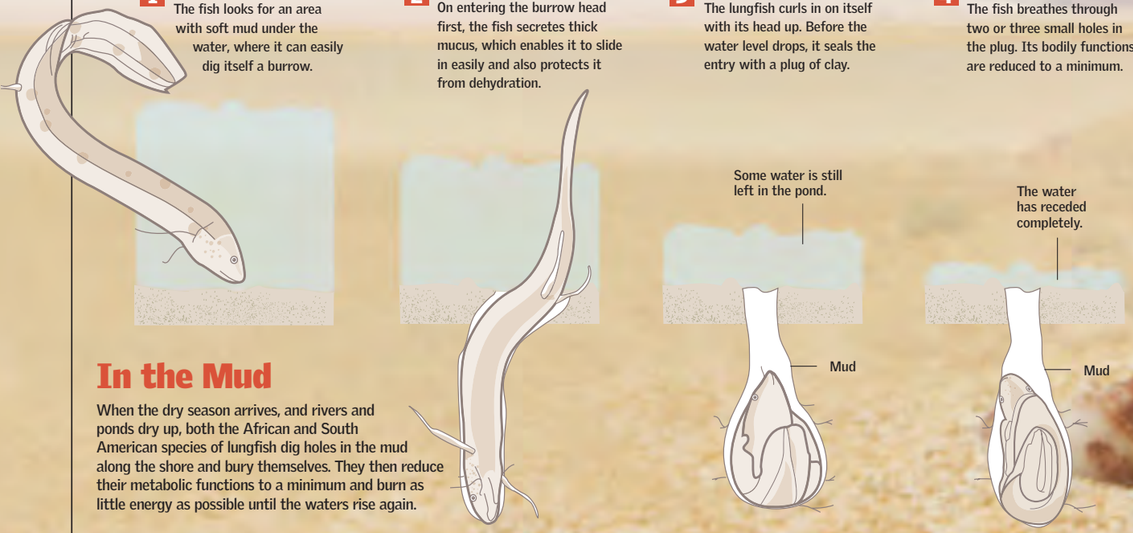
When the dry season arrives, and rivers and ponds dry up, both the African and South American species of lungfish dig holes in the mud along the shore and bury themselves. They then reduce their metabolic functions to a minimum and burn as little energy as possible until the waters rise again.

1 WATER LEVELS DROP
The fish looks for an area with soft mud under the water, where it can easily dig itself a burrow.

2 HEAD FIRST
On entering the burrow head first, the fish secretes thick mucus, which enables it to slide in easily and also protects it from dehydration.

3 TURNING AROUND
The lungfish curls in on itself with its head up. Before the water level drops, it seals the entry with a plug of clay.

4 HIBERNATION
The fish breathes through two or three small holes in the plug. Its bodily functions are reduced to a minimum.



EYES
Large and prominent to provide a panoramic view, they are protected by a delicate layer of skin. The fish rotates its eyes to keep them moist.

WATER RESERVES
Cavities for storing reserves of seawater. This way the gills never dry out when the fish is out of water..

GILLS
Located in a type of cavity that contains both water and air. They can absorb air as long as they are kept moist.

MOUTH AND THROAT
also contain respiratory organs.

FINS
Used for walking and jumping when outside the water, they even enable the fish to climb trees. In water, the fish crawls along the bottom.

VENTRAL DISK
Modified fins act as a lever for the fish to lift itself onto roots and tree trunks.

SKIN
The skin is a respiratory organ and needs to be kept moist. The skin cells are able to accumulate water.

MUSCULATURE
is adapted to its sculpted body to enable it to jump in the mud. This gives the fish its common name.

Atlantic Mudskippers
(Periophthalmus barbarus)

These are the only water-dwelling fish that can adapt to a completely amphibious lifestyle. What's their secret? They accumulate water in their skin and in several special chambers near their gills, which enables them to use their gills outside the water. They live on the coasts of the Indian and Pacific oceans, in southeast Asia, and on the western coasts of Madagascar. They usually swim in shallow waters, holding onto roots and seaweed and raising their heads out of the water. They move about easily on mud and dry land, and they can even climb trees. They can breathe air or water equally well.

Fossils

Lungfish have not evolved in 250 million years.

MUDSKIPPER
Periophtalmus sp.

Habitat	Indian Ocean and the Pacific coasts of Asia
Family	Gobidae
Length	6 inches (15 cm)

Amphibians

POISONOUS FROG
Frogs of the genus Dendrobates secrete a special type of poison that attacks the nervous system.

DISTANT KIN 62-63
BETWEEN LAND AND WATER 64-65
JUMPING ATHLETES 66-67
DEEP EMBRACE 68-69
METAMORPHOSIS 70-71
POISON IN COLOR 72-73
AXOLOTL 74-75
A VERY PECULIAR TAIL 76-77
NEWTS 78-79

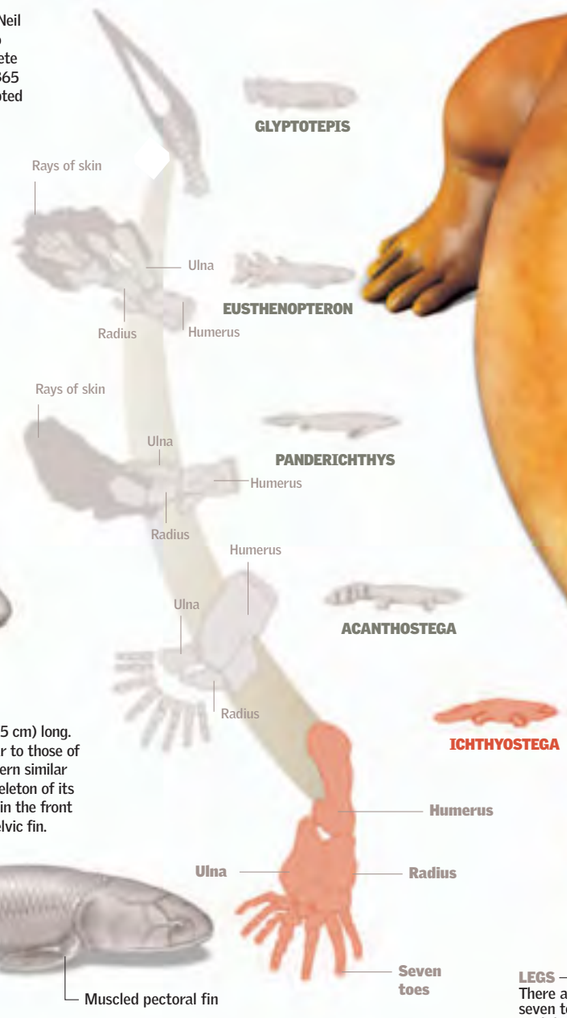
Few groups of amphibians have generated as much scientific interest as frogs of the genus *Dendrobates*, which produce toxic secretions through their skin. All frogs of this genus have spectacular coloring to warn their predators of the danger. One of the most important traits of amphibians (newts, salamanders, frogs, toads, and caecilians) has been their conquest of land. This completely transformed the extremities of these animals, allowing them to move on land instead of swimming. They also had to adapt to take in oxygen through their skin and lungs. Here you will also discover how frogs and toads reproduce and how newts feed, among other curious facts. ●

Distant Kin

The first amphibians evolved from fish with fleshy, lobed fins that resembled legs. They may have been attracted to land as a source for food, but the most important reason for their leaving the water was the instability of the Devonian Period, which drastically affected freshwater environments. During long droughts, the fish used their fleshy fins to move from one pond to another. Oxygen availability was also affected, and this led to more organisms being able to breathe oxygen from the air.

Legs: Evolution

In 2004, American paleontologist Neil Shubin of the University of Chicago offered the scientific community a complete description of a humerus bone that was 365 million years old. The first tetrapods adapted to land exhibited a great variety of leg shapes, sizes, and strengths. After comparing this fossil with that of other tetrapods, scientists concluded that the evolution of the legs and of the muscles necessary for walking began in the water.

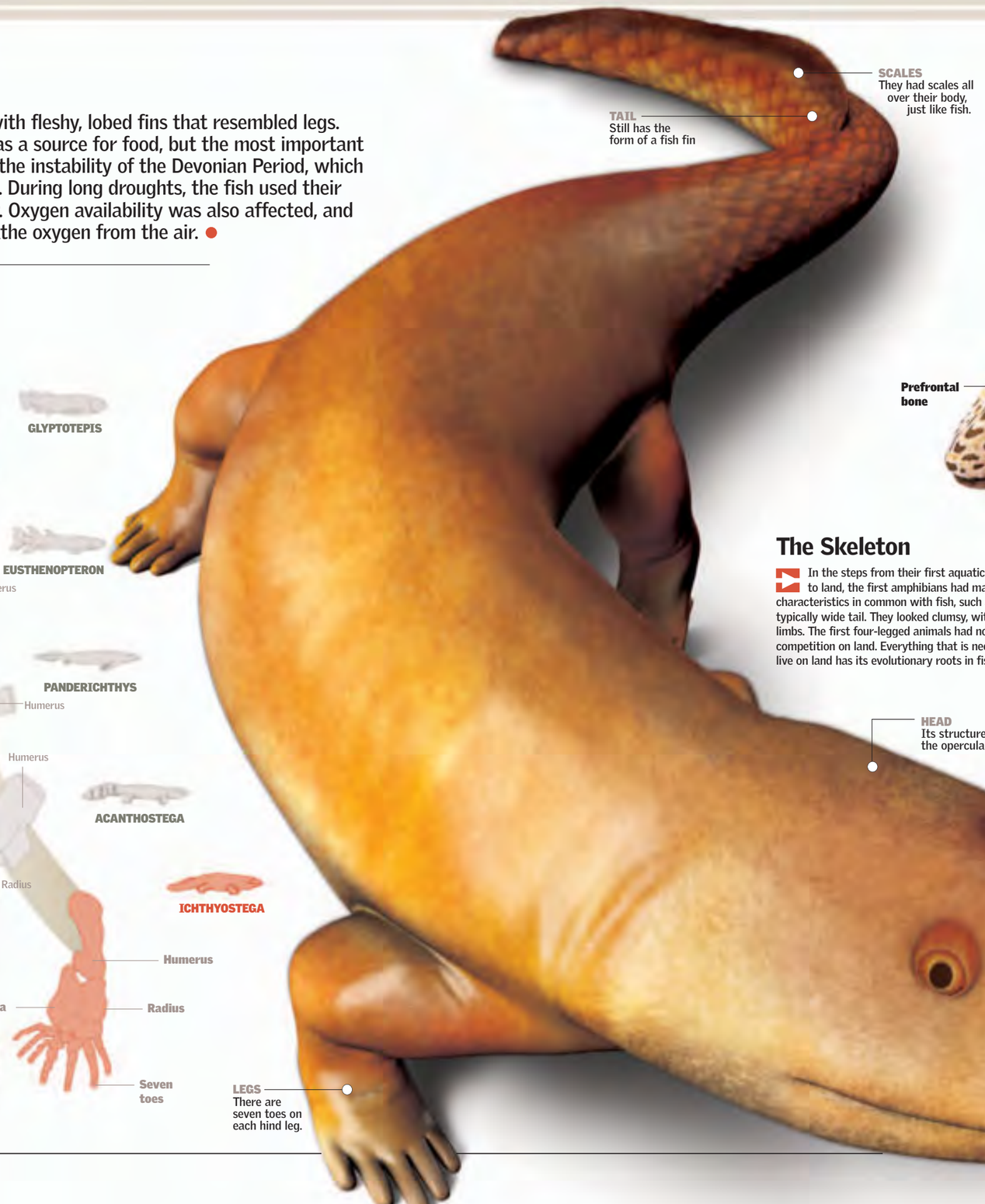


Tiktaalik

A lobe-finned fish from the late Devonian Period, with many tetrapod characteristics. It lived 375 million years ago. Some paleontologists suggest that it was another intermediate form between fish and amphibians.

Eusthenopteron

A relatively large fish, about 29 inches (75 cm) long. Many features of its skeleton were similar to those of the first amphibians; it had a cranial pattern similar to *Acanthostega* and *Ichtyostega*. The skeleton of its fins included a humerus, ulna, and radius in the front fin and a femur, tibia, and fibula in the pelvic fin.

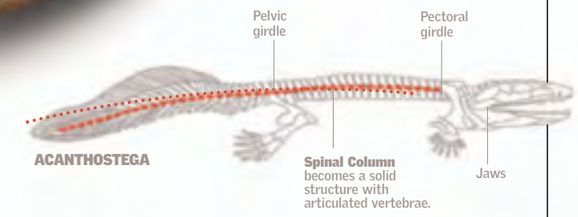


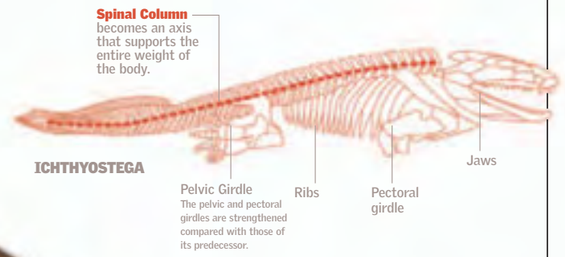
Acanthostega

lived some 360 million years ago. It is considered one of the first amphibians, even though it was not well adapted to land and lived mainly in water. It had gills, like fish, even though it probably also had lungs. Its legs were well developed, but they were not yet fit for moving on land.

The Skeleton

In the steps from their first aquatic habitat to land, the first amphibians had many characteristics in common with fish, such as a typically wide tail. They looked clumsy, with short limbs. The first four-legged animals had no competition on land. Everything that is needed to live on land has its evolutionary roots in fish.





ICHTHYOSTEGA

Scientific name	Ichthyostegopsis
Lived	360 million years ago
Location	Greenland
Length	Up to 3.3 feet (1 m)

Between Land and Water

As indicated by their name (*amphi*, "both," and *bios*, "life"), these animals lead a double life. When young, they live in the water, and when they become adults they live outside it. In any case, many must remain near water or in very humid places to keep from drying out. This is because amphibians also breathe through their skin, and only moist skin can absorb oxygen. Some typical characteristics of adult frogs and toads include a tailless body, long hind limbs, and large eyes that often bulge.

Amphibian Anatomy

Amphibian anatomy has several peculiarities. Larvae, such as tadpoles, have a respiratory system with gills. Most species develop lungs when they reach adulthood. They also have a trachea, pharynx, and saclike lungs, even though skin breathing is at times more important than lung breathing. The heart has two auricles and one ventricle, and the digestive and excretory systems are similar to those of mammals.

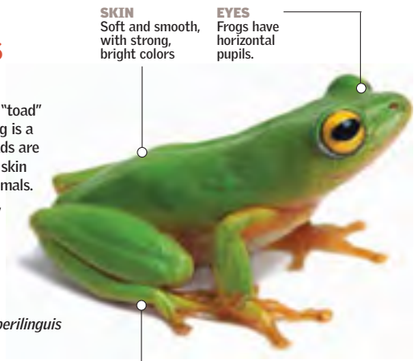
The Skin

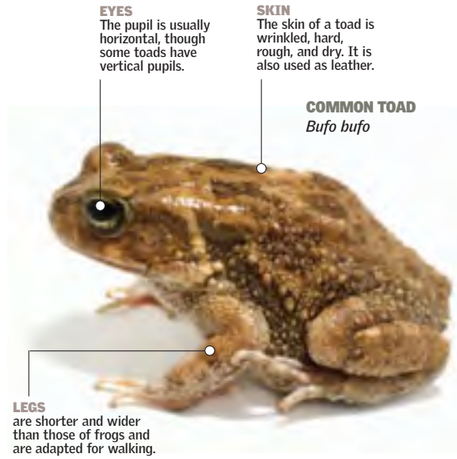
Amphibians breathe through their skin, which is clean and smooth, without hair or scales. They must always keep it moist, because it has a strong tendency to dry out. Even though they have mucous glands that help maintain moisture, amphibians must live in damp places. The skin of most amphibians protects them from possible predators and has poisonous glands that secrete unpleasant and even toxic substances.

VOCAL SACS
Both toads and frogs sing. Even though the sound is produced by their vocal cords, in males the sound is amplified by means of inflatable sacs on each side of the larynx.

Differences Between Frogs and Toads

It is very common to use "frog" and "toad" as synonyms or to think that the frog is a female toad. However, frogs and toads are quite different. Toads have wrinkled skin and short legs, and they are land animals. Frogs are smaller, have webbed feet, and live in the water and in trees.





Nutrition

is based on plants during the larval stage, whereas in the adult stage the main food sources are arthropods (such as insects of the order Coleoptera and arachnids) and other invertebrates, such as butterfly caterpillars and earthworms.

Types of Amphibians

Amphibians are divided into three groups that are differentiated on the basis of tail and legs. Newts and salamanders have tails. They belong to the order Urodela. Frogs and toads, which have no tail except as tadpoles, belong to the Anura group. Caecilians, which have no tail or legs, are similar to worms and belong to the Apoda group.

1 **ANURA**
Tailless

2 **APODA**
Without legs

3 **URODELA**
With a tail

Legs

Frogs and toads have four fingers on each front leg and five on each hind leg. Water frogs have webbed feet; tree frogs have adhesive disks on the tips of their fingers to hold on to vertical surfaces; and burrowing frogs have callous protuberances called tubercules on their hind legs, which they use for digging.

Jumping Athletes

Amphibians of the order Anura are known for their ability to jump high and far. This group includes frogs and toads, and their anatomy helps them to jump. Frogs use their jumping ability to escape from their many predators; they can jump a distance equivalent to 10 to 44 times their body length. When they feel threatened, they can choose to jump into the nearest body of water, where they hide, or they can jump erratically on land to confuse their attacker.

The Frog

Its large eyes help it to locate prey easily. The eyes have lids that protect them from particles in the air or help them see underwater. The frog's smooth skin has glands that moisten it or that secrete toxic or irritating substances. The frog breathes through its lungs and skin. It has a large tympanum, or eardrum, visible on each side of the head and a wide mouth that may or may not have teeth.

1 Jumping

Before the jump begins, the frog tenses the muscles of its hind legs and presses its feet against the ground. As the frog jumps, the legs extend to propel the body forward.

2 Feeding

Amphibians from the order Anura have a varied diet. They feed on insects and small invertebrates such as earthworms, snails, crustaceans, and spiders. Tadpoles are herbivores.

HOW IT FEEDS

1 Adhesion
The insect adheres to the tip of the tongue, which is sticky.

2 No escape
The tongue folds back into the mouth, carrying the insect with it.

Insects found on plants are the favorite meal of frogs.

AT THE TOP
The white-lipped tree frog (*Litoria infrafrenata*) has a maximum length of 3.9 inches (10 cm) and is adapted for mountain climbing, jumping, and moving on flat areas. The pads on the tip of each finger and toe allow it to adhere to many surfaces.

WHITE-LIPPED TREE FROG
Litoria infrafrenata

The toe has a sticky mucous coating.

Spinal column
Its small number of vertebrae give it elasticity in the act of jumping.

Leg
Adapted for jumping and swimming

9 VERTEBRAE
Aside from these, it has a urostyle—a cylindrical bone that results from the fusion of vertebrae.

EYES
During the jump the eyes remain shut.

VISIBLE HUMP

STRETCHED-OUT BODY

FOREFEET
have four fingers and are not as strong as the hind feet.

LEG MUSCLES
tense to carry out the jump.

EDIBLE FROG
Rana esculenta
is found in Europe and also in the United States, Canada, and Asia.

HIND FEET
have five webbed toes.

3 Fall

At this moment, when the frog extends its hind legs, it not only reduces air resistance but also helps with the entry into the water.

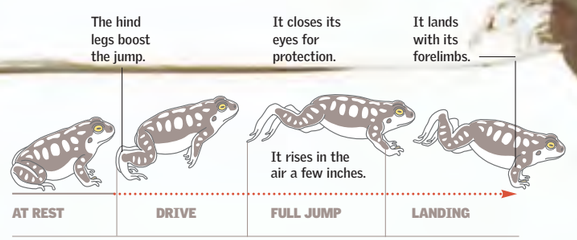
Fall
Each hind leg extends like an arrow.

The Toad

Having characteristics similar to those of frogs, toads can be distinguished by only a few features. Generally, toads are larger, less stylized, and better adapted to living on land. Toads' skin is thicker than that of frogs to prevent drying, and toads are normally covered with warts.

ASIAN TREE FROG
Pedostibes tuberculosus

THE JUMP
The toad's jump covers less distance because of its greater weight and because its legs are not as flexible as those of the frog.



17.5 feet (5.35 m)
THE DISTANCE JUMPED BY AN AFRICAN FROG

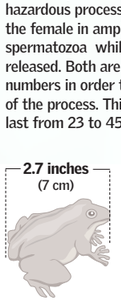
DIVE
The body curves upward when it enters the water.

Deep Embrace

Reproduction by amphibians is usually carried out in the water, where the female deposits the eggs, despite the fact that some species are able to deposit eggs on land. The most favorable time for this activity is during the spring, when the male sings to make his presence known. During mating, also called amplexus, the male positions himself on top and fertilizes the eggs as they come out. Then gelatinous layers absorb water and increase their volume, binding the eggs together in large masses.

Amplexus

Fertilization for the majority of amphibians is external. In this hazardous process, the male, embracing the female in amplexus, discharges spermatozoa while the ovocytes are released. Both are released in great numbers in order to ensure the success of the process. This mating embrace can last from 23 to 45 minutes.



Females are larger than males.

Weight
1.7-5 ounces
(50-100 g)

IBERIAN WATER FROG
Rana perezi

Diet	Carnivorous
Reproduction	Oviparous
Season	Spring

SOME ANURANS CAN LAY UP TO

20,000 eggs.

LIFE CYCLE

The three stages of the life cycle are egg, larva, and adult. The embryos begin to develop within the eggs; then, after six or nine days, the eggs hatch, and tiny tadpoles with spherical heads, large tails, and gills emerge. Once the gills pass their function over to the lungs and the tail of the amphibian has shrunk and disappeared, the young frog enters the adult stage.

A ROMANTIC SONG
The call that a male makes to mate with a female

NUPTIAL PAD
Used by the male to hold onto the female

Four cylindric fingers

MALE FOREFOOT

FEMALE FOREFOOT

EGGS INSIDE THE FEMALE

THE MALE
holds the female and deposits the sperm.

THE FEMALE
lays the eggs in a string.

16 weeks

THE DURATION OF THE CYCLE

Responsible Parents

Some males of frog and toad species play an important role in the protection of the eggs laid by the female. They pick up the eggs and help the mothers, and some even carry the eggs with them until the birth takes place.

EUROPEAN MIDWIFE TOAD
Alytes obstetricans
The male winds up the string of eggs that the female has laid over his hind legs. He carries the eggs for a month, provides them with a moist environment, and leaves them in the water so the young can swim away.

35-60

THE NUMBER OF EGGS THE TOAD CAN CARRY ON HIS BACK

Inside of the egg

The tadpoles are born in the water.

SURINAM TOAD
Pipa pipa
The female goes around in circles, releasing one egg each time. The male places the egg on the female's back, and she covers them with her swollen skin to protect them until they hatch.

The young are identical to their parents.

Hatching egg

Release of the tadpoles

The tadpoles absorb oxygen.

HINDFEET

Metamorphosis

Metamorphosis is the process of transformation experienced by anurans (it can also be observed in amphibians from the order Urodela and caecilians) starting with the egg and ending at the adult stage. When they leave the egg, amphibians have a larval form. They then undergo very important changes in their anatomy, diet, and lifestyle, slowly mutating from their first stage, which is completely aquatic, until they transform into animals adapted to life on land.

Cycle

METAMORPHOSIS
The development of the common European frog from egg to adult takes approximately 16 weeks.

Mother Frog and Her Eggs

Despite the fact that the survival instinct of anurans is not fully developed, frogs and toads somehow take care of their future young. Laying eggs in great quantities ensures that many tadpoles will be able to escape predators who feed on the eggs. The gelatinous layer also protects the eggs from other predators. Some frogs even care for their tadpoles by nestling them on their backs. An example of such a frog is the Surinam toad.

EDIBLE FROG
Rana esculenta

1 Larvae

3 DAYS
The larvae have large heads and are elongated; they have gills and an open mouth that they use to feed.

EXTERNAL GILLS
Three days after leaving the egg, the tadpole acquires gills.

Strategies

Given that there often are not enough bodies of water available (or not enough that are adequate for reproduction), many frogs and toads such as the ones from this species form large proliferation groups. The collective mass of eggs can retain heat better, and that allows the tadpoles to be hatched in less time. Many times frogs and toads use lakes and streambeds that dry out at certain times of the year, because that practice prevents other animals from arriving and eating the eggs and tadpoles.

Gelatinous Capsule

Each egg is wrapped in a gelatinous or jellylike capsule that expands the moment it touches the water and thus increases in volume to protect the embryo.

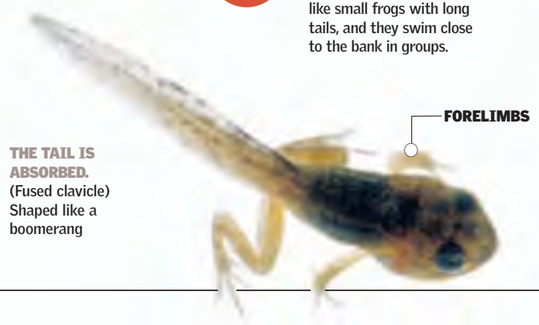
2 Change

4 WEEKS
The external gills are covered by the skin of the body, and they are replaced by internal gills. They feed on algae.

HIND LIMBS
The hind limbs appear as small buds.

3 Change 2

6 WEEKS
The tadpoles begin to look like small frogs with long tails, and they swim close to the bank in groups.



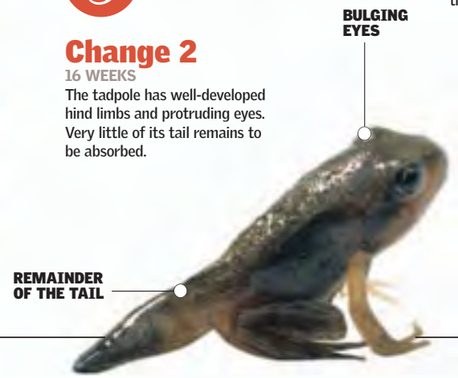
THE TAIL IS ABSORBED.
(Fused clavicle) Shaped like a boomerang

4 Change 2

9 WEEKS
A tissue has divided the atrium (one of the parts of the heart), resulting in a three-chamber heart, which helps with the movement of blood between the heart and the lungs.

5 Change 2

16 WEEKS
The tadpole has well-developed hind limbs and protruding eyes. Very little of its tail remains to be absorbed.



6 Change 2

READY
Adult frogs meet at the pond's bank before abandoning the water for the first time, which they do as a group.

FINGERS
Frogs have four toes on their forefeet and five on their hind feet.

Poison in Color

Not all that glitters is gold, nor is it healthy. The skin of some amphibians has glands that secrete poison. Color is a warning sign, a way of keeping possible attackers away, and also a way to defend territory during mating season. The most dangerous frogs are the poison dart frogs from Central and South America and the mantella frogs of Madagascar. They are a small, very sociable species that live in small groups, are diurnal, and, in some cases, live in trees. ●

POISONED DARTS
The Chocó Indians of Colombia poison the tips of the darts of their blowpipes to hunt. They obtain the toxin by heating a live frog over a fire. In the case of *Phyllobates terribilis*, this yellow frog is so poisonous that rubbing the dart against the back of the frog is enough to make the dart poisonous.

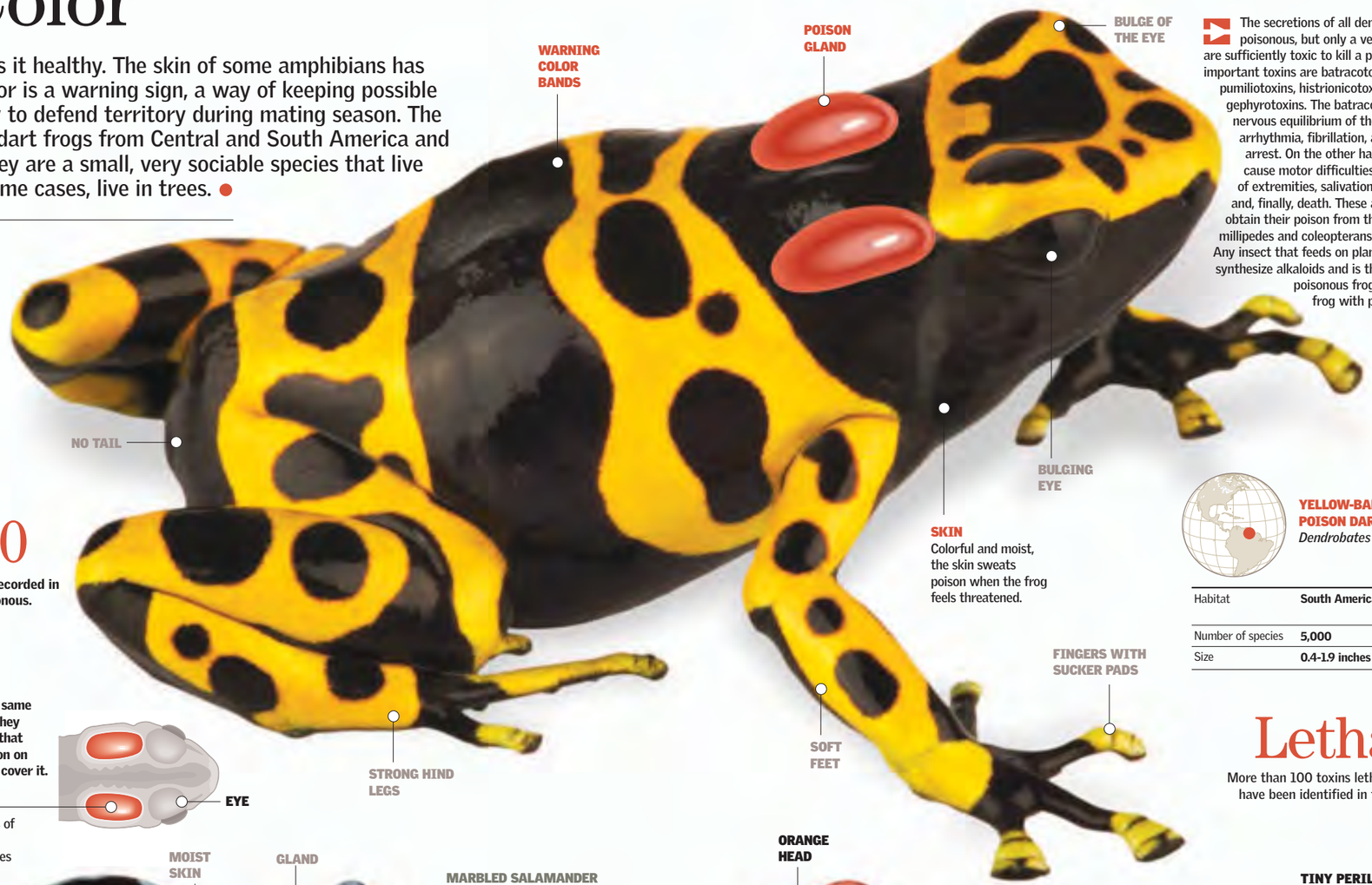
1 **Tadpole.** Has not yet developed the poison at this stage.

2 **Tadpole with legs.** When the color is visible, the poison is deadly.

3 **Adult.** The color is bright and distinct.

About
3,600
species of amphibians recorded in the world are poisonous.

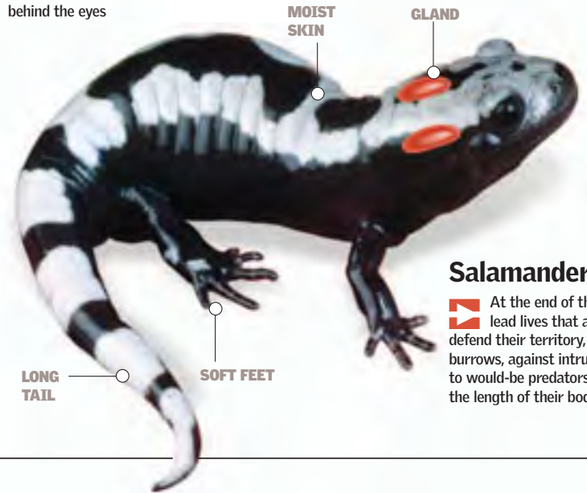
TOXIC TADPOLES
Poison dart frogs, or poison arrow frogs, carry their tadpoles, sometimes one by one, to small isolated ponds (sometimes in tree hollows), where they raise them. There they develop both their color and the poisonous toxins that they secrete from their backs when they feel threatened.



SKIN
Colorful and moist, the skin sweats poison when the frog feels threatened.

GLANDS
function the same as in frogs; they have glands that secrete poison on the skin and cover it.

GLANDS
On both sides of the head and behind the eyes



MARBLED SALAMANDER
Ambystoma opacum
This type of salamander can measure between 2.7 and 4.7 inches (7-12 cm) in length. Its base color is black with silver stripes, which gives the salamander its marbled look and its name.

Salamanders

At the end of their development, these salamanders lead lives that are completely terrestrial. They defend their territory, including the space around their burrows, against intrusion. Their colors act as a warning to would-be predators. Two rows of poisonous glands run the length of their bodies.

Frogs and Mantellas

The secretions of all dendrobate frogs are poisonous, but only a very small number are sufficiently toxic to kill a person. The most important toxins are batracotoxins, pumiliotoxins, histrionicotoxins, and gephyrotoxins. The batracotoxins affect the nervous equilibrium of the body and cause arrhythmia, fibrillation, and cardiac arrest. On the other hand, pumiliotoxins cause motor difficulties, partial paralysis of extremities, salivation, convulsions, and, finally, death. These amphibians obtain their poison from their diet: certain millipedes and coleopterans, as well as ants. Any insect that feeds on plants that synthesize alkaloids and is then ingested by a poisonous frog provides the frog with poison.

YELLOW-BANDED POISON DART FROG
Dendrobates leucomelas

Habitat	**South America**
Number of species	**5,000**
Size	**0.4-1.9 inches (1-5 cm)**

Lethal

More than 100 toxins lethal to humans have been identified in these frogs.

GREEN AND BLACK POISON DART FROG
Dendrobates auratus
Spotted body and variety of colors

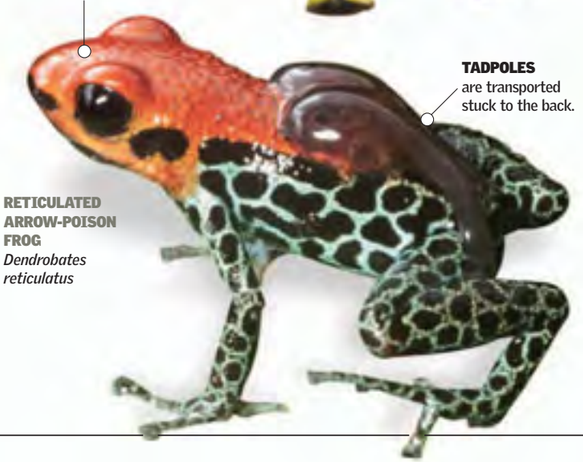
COSTA RICAN VARIABLE HARLEQUIN TOAD
Atelopus varius
Regular red spots

BLUE POISON DART FROG
Dendrobates azureus
The color is bright blue.

THE COLOR OF POISON
In nature, bright, flashy colors usually serve as a warning sign to predators. Thus, a frog can use color to defend its territory from other males during mating season.

ORANGE HEAD

TADPOLES are transported stuck to the back.



RETICULATED ARROW-POISON FROG
Dendrobates reticulatus

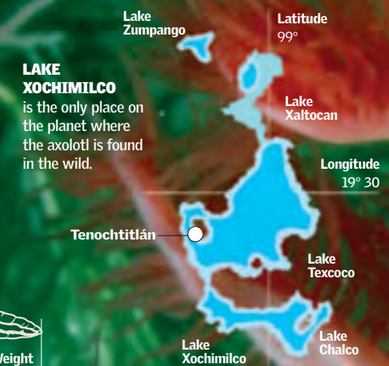
TINY PERIL
The golden poison dart frog is one of the most poisonous animals on the planet. It can kill 10 human beings with the quantity of poison it stores.

Axolotl

This plump amphibian is a classic example of neoteny—the ability to reproduce without developing completely into an adult. The axolotl has a flat tail and large external gills, which most salamanders lose when they reach maturity and begin to live on land. The axolotl is mostly nocturnal and feeds chiefly on invertebrates. It, in turn, can wind up as the prey of a water bird. The axolotl was once considered a delicacy, but it is now legally protected.

AXOLOTL
Ambystoma mexicanum

Habitat	Mexico (Lake Xochimilco)
Habits	Mainly aquatic
Length	10-12 inches (25-30 cm)
Life span	25 years



Neoteny

One of this animal's notable traits is neoteny—that is, reaching sexual maturity while in a larval stage, never experiencing metamorphosis. Neoteny is caused by low levels or the complete absence of thyroxine as the result of a low-functioning thyroid gland. In axolotls, thyroxine can be generated under experimental conditions by administering iodine.

Regeneration

Another trait of the axolotl is its outstanding ability to regenerate its extremities and other parts of the body, including parts of its head. It can regenerate itself through the proliferation of stem cells in the affected area. These cells multiply and differentiate to replace the missing tissue. Interestingly, the ability to regenerate is shared by other amphibians of the order Urodela.

Mythology

In Aztec mythology, the axolotl (*atl* means "water" and *xolotl* means "monster") is the aquatic form of Xólotl, the god for which it is named. Xólotl feared death, refused to accept it, and sought to escape it using his powers of transformation. The legend recounts that, to flee Death, he ran to the water, where he became the fish called axolotl. This action becomes his final metamorphosis, because Death finally finds him and kills him.

12 inches (30 cm)
An adult axolotl can be 10 to 12 inches (25-30 cm) long.

EXTERNAL GILLS
are a trait that most salamanders lose when they reach maturity and begin to live on land.

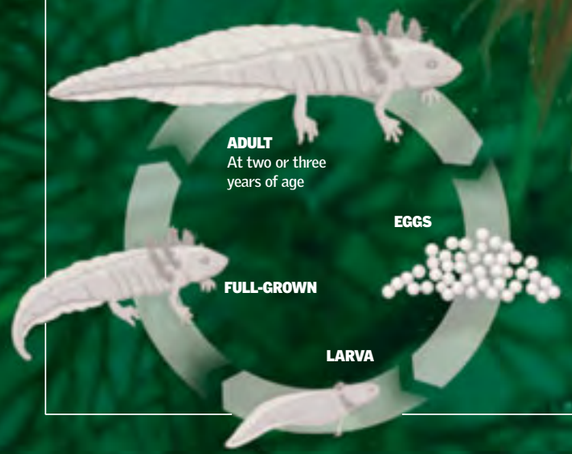
COLORS
Usually they are dark brown with white spots. In captivity or in their natural environment, some are albinos with red or gray gills.

SKIN
Unlike salamanders and other metamorphosed amphibians, axolotls do not shed their skin.

EXTREMITIES
The extremities are fragile and delicate. In albinos, the bones can be seen through the thin, transparent skin. Axolotls have four toes on each front foot and five on each hind foot.

Life Cycle

The female lays a large number of eggs. The time of incubation depends largely on the temperature. At 60° F (16° C), incubation averages 19 days. At the age of six months, the animals are very active swimmers. They reach sexual maturity at one year of age and adult size at between two and three years, never losing certain anatomical and physiological traits of the larval stage.

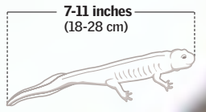


A Very Peculiar Tail

The salamander is an animal of the order Urodela that needs damp places to survive. It lives in a very limited range of areas, and it is highly sensitive to modifications in its natural habitat. Unlike frogs and toads, the salamander keeps its tail when it reaches adulthood. The tail makes up nearly half the length of its body. Salamanders, especially adults, are completely nocturnal. Their movements are slow when they walk or crawl along the ground. During the day they stay hidden under rocks, in underground burrows, and on tree trunks.

COMMON SALAMANDER
Salamandra salamandra

Habitat	**Europe**
Order	**Urodela**
Family	**Salamandridae**



Reproduction may occur in spring, depending on the habitat and the species.

HUMIDITY
is necessary for breathing through the skin.

Anatomy

The head is narrow, with the mouth and eyes smaller than those of frogs and toads. However, in comparison with frogs and toads, the salamander's body is longer, but its feet are similar in size and length. The salamander walks slowly, never reaching great speeds, and its limbs are at a right angle to the body.

HEAD
Its head is smaller than those of frogs and toads because of the loss of bony structures and the presence of cartilage.

TAIL
The salamander has a tail, unlike frogs and toads, which lose their tails on reaching adulthood.

BODY
Long, with 16 to 22 thoracic vertebrae, each one with a pair of ribs.

SKIN
On the back and sides, the skin is smooth and shiny. On the throat and belly, the yellow spots are duller and less numerous.

FEET
Salamanders have four toes on each foot. The salamander pushes its body forward by pressing against the ground.

EYE
Large and bulging, with a dark-brown iris

Tongue pad

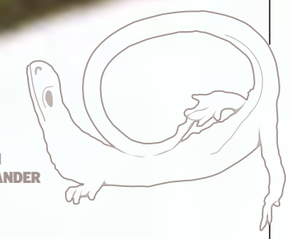
The tongue muscles retract.

Outer section of the tongue

Retractor muscles

Feeding Habits

CWith its long tongue, the salamander can trap its prey in a flash and quickly gulp it down. These carnivorous animals use mainly sight and smell to hunt. Because they are not very active, salamanders need relatively small amounts of food. If they obtain more food than necessary, they store it as fat for lean times.



ITALIAN SALAMANDER

Life Cycle

There are three stages to the life cycle: egg, larva, and adult. The eggs vary in size depending on the species. Larvae have feathery external gills. Metamorphosis lasts until adulthood, when the salamander loses its gills and switches to breathing with lungs.

1 EGG
Hatches into a larva

2 BIRTH
The larva is born with feathery external gills.

3 ADULT
Metamorphosis is completed; the salamander reaches sexual maturity.

CHANGE
The body grows longer; the salamander begins to breathe through the skin and lungs.

LARVA
Metamorphosis begins; the salamander loses its gills and switches to breathing air.

Defense

The Italian spectacled salamander has two ways of avoiding its enemies. It plays dead, or it curls its tail forward. Other species defend themselves by using a toxic substance produced by glands or by breaking off the tail, which continues to move on its own and confuses the predator.

38 months
GESTATIONAL PERIOD

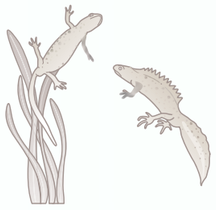
LARGE ALPINE SALAMANDER
Salamandra lanzai
is known for having the longest gestational period of all animals, even longer than that of elephants.

Newts

Along with salamanders, newts are the most primitive of terrestrial vertebrates. Of the three main surviving groups of primitive amphibians, newts most closely resemble the animals from which all amphibians are descended. Some of their habits are also more complex and varied. Most of the time they live on land, but during the mating season they return to the water. Unlike frogs and toads, newts and salamanders keep their tails as adults. They are found in temperate regions of the Northern Hemisphere.

Courtship and Reproduction

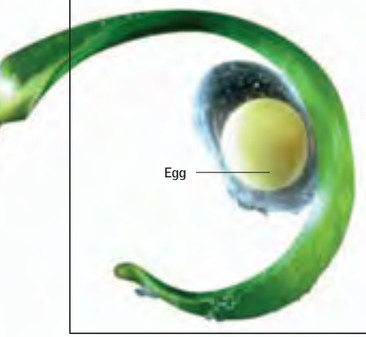
Courtship and mating involve a showy exhibition by both male and female. The male must find a female of the same species and bring her a packet of sperm, which he deposits on the ground or in a pool. Fertilization is internal, and the female gathers the packet into her cloaca.



1 DANCE
Males are attracted by the female's belly, swollen with eggs. The males draw her attention with their showy pigmentation and the flexible crest along their back and tail.

2 EXHIBITION
The male swims in front of the female, displaying his nuptial attire. He raises the toothed crest on his back and slaps his tail while producing secretions from his cloacal glands.

3 CONNECTION
The male deposits his packet of sperm and then gently guides the female toward it, pushing her with his side. The female gathers the packet into her cloaca.



4 EGG LAYING
After the eggs are fertilized, the female finds a place to deposit them, attaching them to underwater vegetation or rocks.

NEWTS

Habitat	**Northern Hemisphere**
Number of species	**360**
Order	**Urodela**

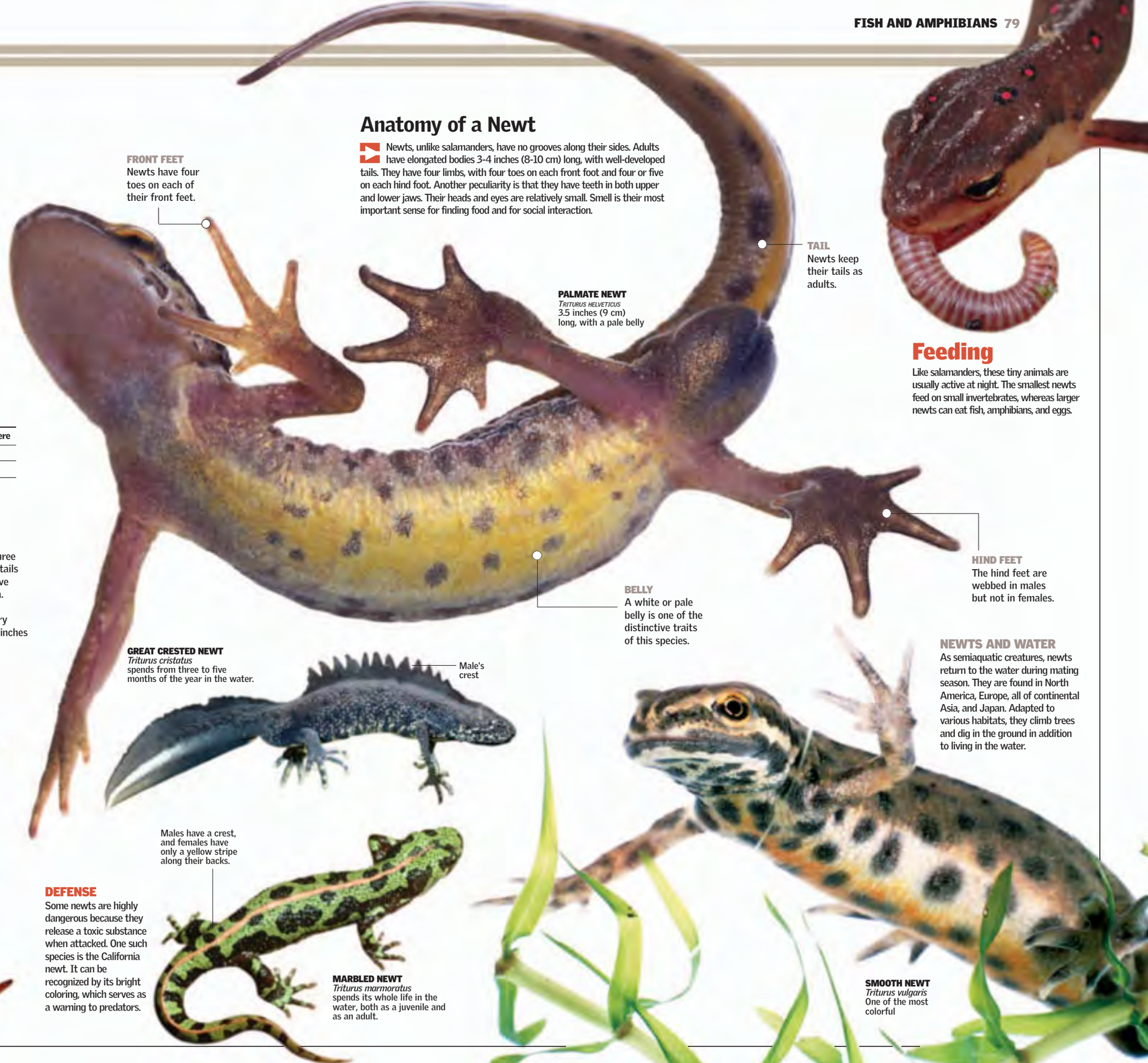
Newt Species

Amphibians are divided into three groups, distinguished by their tails and legs. Newts and salamanders have tails and belong to the order Urodela. Some produce toxic substances for defense from predators. They are very small; the largest newt may reach 6 inches (15 cm) in length.

EASTERN NEWT
Notophthalmus viridescens
The larvae go through a special juvenile stage called the "red phase."

DEFENSE

Some newts are highly dangerous because they release a toxic substance when attacked. One such species is the California newt. It can be recognized by its bright coloring, which serves as a warning to predators.



Anatomy of a Newt

Newts, unlike salamanders, have no grooves along their sides. Adults have elongated bodies 3-4 inches (8-10 cm) long, with well-developed tails. They have four limbs, with four toes on each front foot and four or five on each hind foot. Another peculiarity is that they have teeth in both upper and lower jaws. Their heads and eyes are relatively small. Smell is their most important sense for finding food and for social interaction.

Feeding

Like salamanders, these tiny animals are usually active at night. The smallest newts feed on small invertebrates, whereas larger newts can eat fish, amphibians, and eggs.

NEWTS AND WATER

As semiaquatic creatures, newts return to the water during mating season. They are found in North America, Europe, all of continental Asia, and Japan. Adapted to various habitats, they climb trees and dig in the ground in addition to living in the water.

People, Fish, and Amphibians

SALMON FISHING
The salmon industry has become a true economic and social phenomenon.

MYTH AND LEGEND 82-83
LARGE-SCALE CATCH 84-85
LURE, FLIES, AND BAIT 86-87
ENDANGERED SPECIES 88-89
DRAMATIC DECLINE 90-91

The future of many fish and amphibians is uncertain because some species face fishing nets, loss of habitat, and the invasion of species cultivated by humans. In other areas acid rain is affecting the wildlife of lakes, rivers, and oceans. Fish in particular are very sensitive to chemical substances in the water. As for the world population of amphibians (more than 5,000 species of frogs, toads, salamanders, and caecilians), one third of all species are endangered. Even though experts identify loss of habitat as the main culprit, it is possible that a little-known aggressor—a recently identified illness caused by a chytrid fungus—could be the quickest killer of all. Many similar facts and figures are quite surprising. ●

Myth and Legend

Gods, demigods, princes in disguise, and religious symbols. In the field of myth, fish and amphibians embody powerful, mysterious forces of nature. Because they are aquatic, these smooth-skinned creatures are associated with "primordial waters." Thus, they symbolize the origin of life and resurrection. Through ancient texts, artifacts, and murals, we know that throughout history, many of these creatures have been regarded as supernatural and auspicious.

FISH IN RELIEF
A mural featuring fish in bas-relief, a sample of symbolism from the early Christians

Christianity

The fish is one of the most important symbols used by early Christians. It may have been inspired by the miraculous multiplying of the loaves and fishes or by the meal shared by the seven disciples on the shores of the Sea of Galilee after the resurrection. But its popularity would seem to stem from the well-known acronym of five Greek letters that spell the Greek word for fish: *ichthys*. These words briefly and concisely describe Christ's character, as well as the Christians' beliefs about Him: Iesous Christos Theou Yios Soter-that is, Jesus Christ, Son of God, Savior. It is believed that the early Christians traced two concave lines in the sand, which crossed to form a fish. The anchor, closer to a cross, was also used as a symbol.

EARLY CHRISTIANITY
Basilica of Aquileia
Detail of a fish in one of its mosaic floors

The Americas

Challwa is the Quechua name for fish in Andean traditions. In the beginning there was not a single fish in the sea, because fish belonged exclusively to the goddess Hurpayhuachac, who raised them in a small well in her house. Once the god Cuniraya Viracocha, who was courting one of Hurpayhuachac's daughters, became angry with the goddess and threw her fish into the ocean. In that instant the oceans were populated, and humankind was now able to rely on this new source of food. A few fish keep sacred characteristics. An example is the golden croaker, which some peasants claim to have spotted at Lake Orovilca in Ica. In Central America, the Maya included the toad in the Popol Vuh, or Book of Creation. The axolotl takes its name from the god Xólotl ("monster" in Nahuatl), whose feet were backward.

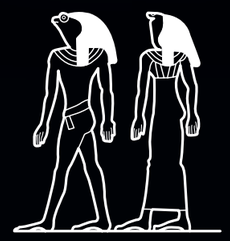
XÓLOTL
Nahuatl name for the brother of Quetzalcóatl
The axolotl, *Ambystoma mexicanum,* is an amphibian native to Mexico that has divine origins, according to the ancient Maya.

Trident
The symbol of sea gods. Poseidon could crumble cliffs or calm the ocean's water with one blow from his trident, as with a magic wand.

GREECE
Poseidon (Neptune) calming the waves as represented by a marble statue in the Louvre Museum in Paris

Greek

The Greek gods of the sea represent the most elementary forces of nature. The Greeks are known for originating many myths, such as that of Poseidon (Neptune in Roman mythology), a brother of Zeus and son of Cronus and Rhea. Not only did Poseidon have power over the waves, but he could also unleash storms, smash cliffs, and cause springs to burst forth from the ground. The sovereign of the seas, he was portrayed holding a trident, a tool used by tuna fishers, and riding a chariot, surrounded by various fish and sea animals. His son, fish-tailed Triton, could control the waves by blowing a conch shell. Other sea-dwelling creatures included the Nereids (with bodies covered in scales) and the seductive mermaids, who captivated mortals.



Egyptians

Egyptian life revolved around the Nile River, which was considered the source of life and the sole basis for the existence of this ancient civilization. The river ensured harvests and provided a habitat for many types of small animals, including frogs and snakes. In mythology, this pair of gods (Khnum and Naunet) represent the primordial waters.

China

According to Chinese mythology, the half-human and half-amphibian couple Fu Hsi and Nü Kua founded the Chinese civilization after a great flood in the year 3222 BC. Fu Hsi is also considered the originator of the *I Ching*.

CHINA
Lacquer tray from the Qin dynasty, with fish motif

The Frog Prince

Throughout history, the toad has been regarded as a symbol of the unsightly. A folktale tells the story of a frog prince who finally regains his human identity. One day a princess is moved by a sacrifice from the toad and kisses it. This act returns the animal to its original state, that of a handsome Prince Charming, who had been the victim of a spell.

Large-Scale Catch

The international demand for fish and shellfish has encouraged the use of highly efficient fishing vessels and techniques. The use of these vessels and techniques, however, has brought about increasing destruction of these resources and of the environment. Every year, fishing nets kill more than 300,000 whales, dolphins, and porpoises worldwide. The greatest threat facing many species is to become enmeshed in the nets. ●

Traditional Fishing

Traditional fishing is a widespread, small-scale activity practiced directly by fishermen using selective fishing techniques. Such harvesting of fish and shellfish is carried out with equipment such as harpoons, hand nets, fishing rods, and fish traps. The vessels may include anything from pirogues to small motorboats.

Local vessels
fish in surface waters. The fish they catch are usually sold in the surrounding area.

71.5 billion dollars
THE RECORD AMOUNT OF MONEY EARNED BY THE FISHING INDUSTRY

Algae supply
Collected as food or fertilizer, algae also provide the vegetable gelatin used to make ice cream and toothpaste.

Stone traps
strand schools of small fish when the tide goes out.

Raking cockles
Cockles and other shellfish can be gathered at low tide by raking the sand.

Net traps
are a series of cone-shaped nets with a cylinder at one end. They trap fish that swim with the current.

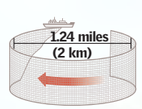
Commercial Species

Of the 20,000 known species of fish, only 300 are targeted for catching. Six of these represent half of the total catch.

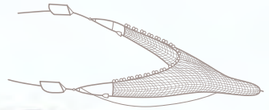
Commercial Fishing

Commercial fishing fleets use advanced technology to detect schools of fish, and they use enormous nets of three types: mesh nets, dragnets, and sweep nets. Fish species that are not used for human consumption are also targeted commercially.

Purse seines, or surrounding nets
hang from floats and are dragged in a circle around a school of fish. Then they are closed at the bottom. These nets are ideal for catching surface species such as tuna and sardines.



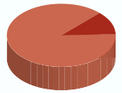
Trawl nets
consist of a cone-shaped body closed by a sack in which the fish are gathered. These nets are maneuvered from one or two ships.

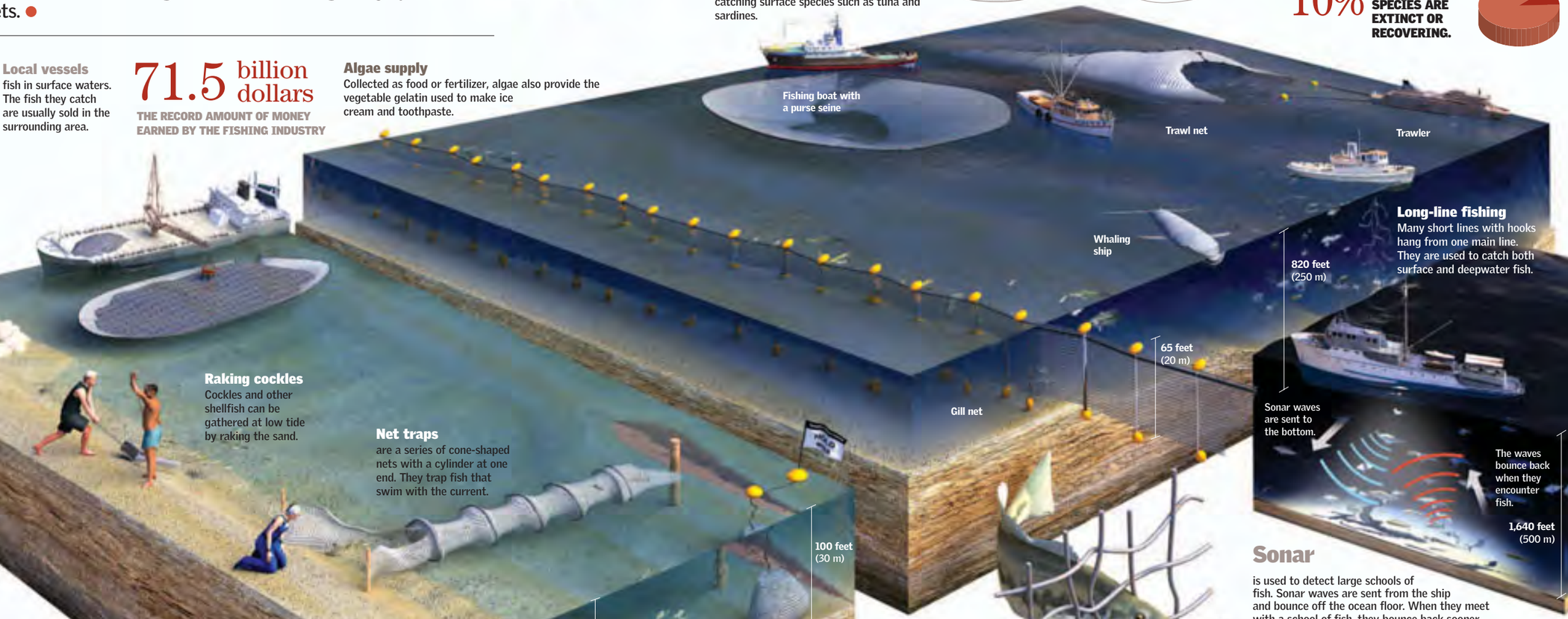


Overfishing

The fishing industry is an important source of food and employment around the world, and it provides the world's population with 16 percent of all animal protein consumed. However, environmental pollution, climate change, and irresponsible fishing practices are taking their toll on the planet's marine resources.

10% **OF ALL SPECIES ARE EXTINCT OR RECOVERING.**





Sonar

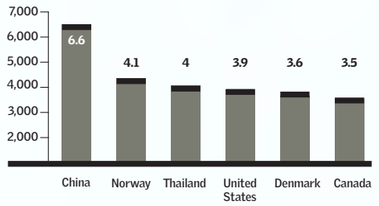
is used to detect large schools of fish. Sonar waves are sent from the ship and bounce off the ocean floor. When they meet with a school of fish, they bounce back sooner.

Bag net
This net is used to catch lobsters, shellfish, and fish. The opening is designed so that the animal can enter the net easily but cannot get out.

Gill nets
hang below the sea surface like curtains, moving to the rhythm of the tides. Besides capturing fish, though, they attract and catch many sea mammals and aquatic birds, which then die.

Great Producers

Fishing is an important source of food and employment all over the world. These figures are in millions of dollars.



Lures, Flies, and Bait

To spot, watch, cast the bait, and catch the fish. Humans and fish, face to face in hand-to-hand combat. Every fisherman or fisherwoman is a hunter, and knowledge of the prey is the basis of success. To catch fish, it is necessary to know their habits and preferences. Fishing methods, from fly-fishing to the use of cutting-edge technology, such as that used to catch tuna, depend on the area, the fish species, and available resources. Choosing the right morsel to tempt the fish (whether real or artificial bait) is another important decision. The key is to know which bait to use among the wide variety available and how to present it. ●

Where to Find Them

Knowing how fish breathe can be very useful for finding them. Arctic char, salmon, and most trout require well-oxygenated waters. They generally live in cold rivers at specific elevations, where the water is clear and clean.

Fresh water

IS THE TYPE OF WATER WHERE MOST SPORTFISHING TAKES PLACE.

Adipose fin, present only in the Salmonidae family

The tail has many spots, and they clearly differentiate the rainbow trout from the common trout.

Wild specimens are thinner than those in breeding farms.

2.7 inches (7 cm)

9.8 inches (25 cm)

Rainbow Trout

Oncorhynchus mykiss

The most popular species for sportfishing, this trout looks athletic and elegant, and it will attack anything that looks like food.

Its tail is square-shaped and clearly forked.

Fins with white borders are characteristic of this species.

39 pounds (18 kg)

TROUT COME IN DIFFERENT SIZES, FROM 3.5 OUNCES (100 G) TO 39 POUNDS (18 KG).

Fishing with a hook

This hook holds a piece of food that is tempting to the fish, so that when the fish bites, it will be hooked. Hooks are tied to a line connected to the fishing rod.

1 CASTING
Once the fish is targeted, it only takes one or two tries for the animal to become suspicious.

Waders allow the fisherman or fisherwoman to approach and make the crucial cast.

Camouflaged jacket to avoid frightening the fish

2 ACTION
The fish has seen the fly. The fish turns toward the fly, and when it takes the lure, the fishing line must be reeled in quickly.

3 COMBAT
Once it has taken the lure, the trout begins to fight by diving and "sprinting" at high speed.

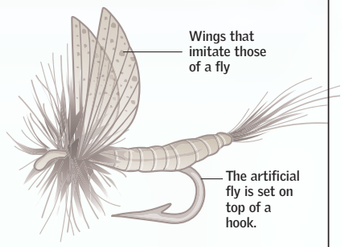
They hear the lure.

SUCCESS DEPENDS ON BOTH THE LOOK AND THE SOUND OF THE LURE.

Rainbow trout can be recognized by the red spot on the operculum bone.

Fishing Strategies

Fishing with a fly, with a hook, with bait, and with lures. Every sportfishing species has its own challenges and thus demands distinct strategies.



Fly-fishing

is the most popular method among those fishing for rainbow trout. As the trout feed on surface insects, they are attracted by artificial flies that the fishermen cast.

Fishing with bait

These are natural baits placed on the hook for the fish to bite. The favorite baits for trout are fish eggs and worms, which are used with small sinkers tied to the fishing line.

Fishing with lures

Lures are objects used as bait to attract fish. They basically consist of a hook and some element that deceives the fish. They are used to capture Arctic char, anchovies, tiger shovelnose catfish, and trahiras.

Underwater, this fish can be identified by its white throat.

2.3 inches (6 cm)

7.8 inches (20 cm)

Brook Trout

Salvelinus fontinalis

These fish are also known as speckled trout. When spawning season begins, they tend to form schools that travel as a group.

Fishing with floats

Fishing with floats and bottom fishing fall in the category of lure casting. This is a static type of fishing—that is, once the lure is cast, one waits for the fish to bite.

Endangered Species

Indiscriminate hunting, overfishing, and pollution of the oceans have pushed many species to the brink of extinction. Sharks and rays are among the first marine life-forms to be systematically studied, and 20 percent of their 547 species are in danger of disappearing. Slow-growing species are especially susceptible to excessive fishing.

Fish in Danger

The situation is especially critical for angel sharks (*Squatina squatina*) and for the common, or blue, skate (*Dipturus batis*). The angel shark has now been declared extinct in the North Sea (after having been moved from "vulnerable" to "critically endangered" status), as has the common skate (which has been moved from "endangered" to "critically endangered"). The common skate is very scarce in the Irish Sea and in the southern part of the North Sea. As fishing operations have moved to deeper waters, the gulper shark (*Centrophorus granulosus*) has also suffered a substantial decline, and it is now in the "vulnerable" category.

HUMPHEAD WRASSE
Cheilinus undulatus

Status	**Endangered**
Cause	**Pollution**
Range	**Pacific and Indian oceans**

This fish lives in Indian Ocean coral reefs. A giant among reef fish, it can reach up to 7.5 feet (2.3 m) in length and can weigh as much as 420 pounds (190 kg). Its meat is prized for its flavor and texture. In many Eastern cultures, the humphead wrasse is considered highly valuable, and only the most privileged members of society can afford it.

PERSIAN STURGEON
Acipenser persicus

Status	**Endangered**
Cause	**Overfishing**
Range	**Caspian Sea**

These fish swim upriver to spawn. Their eggs are highly desirable as caviar. This is one of five species of sturgeon caught wild in the Caspian Sea. It can reach a length of 26 feet (8 m) and can weigh as much as 1,760 pounds (800 kg).

ANGEL SHARK
Squatina squatina

Status	**Critically endangered**
Cause	**Overfishing**
Range	**Mediterranean Sea and Black Sea**

This shark was once a common predator in the North Atlantic, the Mediterranean, and the Black Sea. In the Black Sea, overfishing is especially excessive. In the last 50 years, the angel shark's population has declined dramatically; it has been declared extinct in the North Sea and has disappeared from many areas of the Mediterranean.

YELLOW-CROWNED BUTTERFLY FISH
Chaetodon flavocoronatus

Status	**Vulnerable**
Cause	**Pollution**
Range	**Guam**

It lives only in Guam, in the western Pacific, and only in coral reefs, especially black coral. From time to time this rare fish turns up on the aquarium market. In reality, little is known about the fish and its biology.

PYGMY SEAHORSE
Hippocampus bargibanti

Status	**Endangered**
Cause	**Pollution**
Range	**Caribbean Sea**

Most seahorses are quite small, from the dwarf seahorse in the Gulf of Mexico, at 1 inch (2.5 cm), to the giant seahorse in the Pacific, at 13.7 inches (35 cm). In European waters, seahorses have an average length of 6 inches (15 cm). They use color as protection from the fish and fauna that share their habitat.

WHALE SHARK
Rhincodon typus

Status	**Endangered**
Cause	**Indiscriminate fishing**
Range	**Warm seas**

Although it is recognized as the largest fish in the world, little is known about the whale shark. It can grow to a length of nearly 60 feet (18 m), and it lives in warm seas all over the world. This fish takes some time to reproduce because females do not reach sexual maturity until they are 20 years of age.

COMMON SKATE
Dipturus batis

Status	**Vulnerable**
Cause	**Overfishing**
Range	**Eastern Atlantic**

This fish can reach a length of 8 feet (2.5 m). It has disappeared from many areas of Europe, where it was once common. It is still fished commercially, however. The common skate's large size makes it easy to catch in nets. It lives in the eastern Atlantic, the western Mediterranean, and the western Baltic Sea.

DWARF SEAHORSE
Seahorses eat mainly small crustaceans (copepods, amphipods, isopods, and ostracods), which it sucks into its tubular mouth.

Dramatic Decline

Amphibians are considered by scientists to be the best natural indicators of an ecosystem's health. They are in a catastrophic decline: of all amphibian species, 7 percent are in critical condition, compared with 4 percent of mammals and 2 percent of birds. Of the 5,700 known species of amphibians, 168 have disappeared, and 1 species in 3 is in danger of suffering the same fate. Most of this decline—a phenomenon comparable in proportion to the disappearance of the dinosaurs—has taken place during the past 20 years.

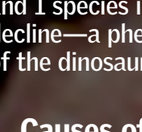
Causes of Danger

The most important cause of the loss of species is the destruction of habitat through water and air pollution. Because most amphibians depend on fresh water to live, they suffer the effects of pollution before other forms of life. This makes them indicators of the condition of the environment. In America and Australia, scientists have identified a fungus that causes a disease called chytridiomycosis. This disease among frogs and toads has caused the amphibian population to decline by over 50 percent. This fungus advances 174 miles (28 km) per year and is lethal.

COSTA RICAN VARIABLE HARLEQUIN TOAD
Atelopus varius

Status	**Critically endangered**
Cause	**Pollution**
Range	**Costa Rica, Panama, and Colombia**

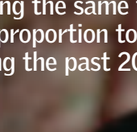
This critically endangered species is highly sought after for its bright colors, which have led to its illegal hunting. At the same time, the toad's habitat is being destroyed by deforestation.



SPOTTED SALAMANDER
Ambystoma maculatum

Status	**Endangered**
Cause	**Deforestation and pollution**
Range	**Eastern United States**

Because of its forest habitat, urban growth and deforestation directly affect this salamander species, and so does environmental pollution. These are the factors that have brought about its endangered status.



CRAUGASTOR TABASARAE
Craugastor tabasarae

Status	**Critically endangered**
Cause	**Disease**
Range	**Panama**

This fish is critically endangered because its population has declined approximately 80 percent over the past three generations. This reduction is attributed to the fungus *Batrachochytrium dendrobatidis*, and it appears to be irreversible.

GOLDEN TOAD
Bufo periglenes

Status	**Extinct**
Cause	**Pollution**
Range	**Costa Rica**

The cause of the disappearance of this species is not yet known. There is speculation that the toad's extinction could have been caused by acid rain or by small variations in the environment.

PERU STUBFOOT TOAD
Atelopus peruensis

Status	**Critically endangered**
Cause	**Infectious disease**
Range	**Peru**

In the past 10 years, the population of this amphibian has declined by 80 percent. The species is now critically endangered. It seems that this animal is disappearing because of a fatal infectious disease that affects amphibians and that is caused by a fungus of the Chytridiomycota order.

COSTA RICAN VARIABLE HARLEQUIN TOAD
Atelopus varius

7%

OF SPECIES ARE ENDANGERED.

KAISER'S SPOTTED NEWT
Neurergus kaiseri

Status	**Critically endangered**
Cause	**Illegal trade**
Range	**Iran**

This newt is endangered because the range of its habitat is less than 60 miles (100 km). The entire population of the species lives within an area of 4 square miles (10 sq km). Both the length and the quality of its life are declining, in addition to a decrease in the number of mature specimens because of the illegal pet trade.

MEXICAN AXOLOTL
Ambystoma mexicanum

Status	**Endangered**
Cause	**Predation**
Range	**Mexico**

The only natural habitat of the axolotl is Lake Xochimilco in the state of Puebla, Mexico, where it is very scarce. Foreign species such as koi and carassius, which were introduced by humans, prey on axolotl eggs.

DUNN ROCKET FROG
Colostethus dunni

Status	**Endangered**
Cause	**Chytridiomycosis**
Range	**Venezuela**

This frog is considered critically endangered because of a drastic, 80 percent decline in its population in the past 10 years. The devastation of the species is attributed to chytridiomycosis.

Glossary

Abyssal Fish

Rare species that inhabit depths of 8,200 feet (2,500 m) and below, where no light reaches. They have peculiar shapes, with large heads and strong teeth for eating other fish, because no vegetation grows at those depths. They attract prey with lure organs consisting of photophores that shine in the darkness.

Actinopterygii (Ray-Finned Fish)

Class of fish distinguished mainly by having a skeleton with bony spines in the fins. They have a cartilaginous skull and only one pair of gill openings covered by an operculum.

Adipose Fin

Small, fleshy lobe located behind the dorsal fin in certain groups of bony fish (for example, in Salmoniformes).

Amphibians

Animals with a double life. The young live in the water, and the adults live on land. Many need to stay near water or in damp places to avoid drying out. This is because some species breathe mainly through their skin, which can absorb air only when damp.

Ampullae of Lorenzini

Organs in sharks for detecting signals emitted by potential prey.

Anadromous Fish

Fish that reproduce in fresh water and live in the ocean as adults. Salmon are one example.

Anaerobic

Breathing process that does not require oxygen.

Anal Fin

Unpaired fin located in the middle ventral part of the fish above the anus.

Anguilliformes

Fish with a long, slender body without appendages, including eels and morays.

Aquaculture

The raising of aquatic organisms, including fish, shellfish, crustaceans, plants, and seaweed. These organisms are usually used as food for humans or animals.

Barbel

Fleshy filament that grows from the lower jaw of certain fish, such as sturgeon, catfish, and cod.

Bathypelagic

Fish that live at ocean depths below the mesopelagic zone, where light cannot penetrate.

Batrachians

Another name for amphibians. It comes from Batrachia, an old name for the class Amphibia. This nomenclature is considered out of date.

Benthic

Relating to the environment or habitat consisting of the ocean floor or of the organisms (benthos) that live buried in (endobenthic), on (epibenthic), or near the bottom.

Benthopelagic

Relating to organisms that are found either on the ocean floor or in open water. Usually refers to fish and crustaceans of deepwater environments.

Bioluminescence

Property of living beings that can produce light.

Bony Fish

Fish with bony skeletons and jaws. Their skeletons are relatively small but firm. They have flexible fins that allow precise control of their movements.

Bony Plates

Formations that grow from the skin and have a protective function for certain species. They usually cover the most sensitive parts of the fish, especially the head, although they can be found along the entire body, as in the case of the Placoderms.

Cartilaginous Fish

Fish with skeletons made of cartilage, such as the Elasmobranchii, a group that includes sharks and rays.

Caudal Fin

Unpaired fin at the lower end of the body, forming the tail fin in most fish.

Complete Metamorphosis

Phenomenon where the adult form of an animal looks nothing like the immature form; examples are frogs and toads.

Continental Shelf

Zone of the seafloor of variable dimensions, characterized by a slight slope and extending from the low tide mark to a depth of approximately 660 feet (200 m).

Ctenoid

Type of scale in which the free edge has spines.

Cycloid

Type of scale in which the free edge is rounded.

Diphycercal

Type of tail in which the spinal column extends to the ends of the tail, and the fin is symmetrical above and below.

Diversity

Degree to which the total number of individual organisms in an ecosystem is distributed among different species. Minimum diversity is reached when all the organisms belong to one species. Maximum diversity is reached in stable natural environments with a maximum variation in the substrate and environmental conditions.

Dorsal Fin

Unpaired fin located on the back, which keeps the fish in a stable position.

Eclosion

The moment when the embryo hatches from the egg.

Electric Organs

Organs of some species, such as electric rays and electric eels, specially adapted to discharge electric current.

Epipelagic

Relating to organisms that live in open water away from the ocean floor, from the surface to depths of approximately 660 feet (200 m).

Estuary

A coastal body of water, partly closed but open to the ocean, where fresh water and salt water mix.

Exothermic

An organism that cannot regulate or maintain its own body temperature is said to be exothermic. The organism's internal temperature depends on the temperature of its environment.

External Fertilization

Fertilization of eggs that takes place outside the female's body. The male releases sperm over the eggs after the female deposits them. The eggs are exposed to the outer environment.

Filterers

Fish that have evolved to take in water and use filters in their mouth or gills to extract from it only the nutrients they need.

Fishhook

Fishing implement, usually made of steel, consisting of a small bar bent in the form of a hook and tied to a fishing line. Fishhooks have different shapes depending on the type of fish they are designed to catch. The hook also carries bait to attract the prey.

Flatfish

Fish that have adopted a flat shape and live on the seafloor. They have both eyes on the same side of the head, a twisted mouth, and pectoral fins on top of the body. The "blind" side of the fish is in contact with the seafloor. Sole is one type of flatfish.

Flying Fish

Exocoetids, or flying fish, are a family of 70 species of ocean fish in nine genera. They are found in all the oceans, especially in warm subtropical and tropical waters. Their most notable characteristic is their unusually large pectoral fins, which enable them to glide through the air for short distances.

Fossil

Remains or impressions of former living beings that are preserved from past geological ages.

Fry

Newly hatched fish whose shape resembles that of adults of the same species.

Ganoid

Type of scale made of shiny, enamel-like material (ganoin) formed in successive layers over compact bone. The extinct fish Palaeospondylus had this type of scale. The only modern fish with ganoid scales are gar, bowfin, and reedfish.

Gill Arch

Bone that anchors the gill filaments or spines.

Gills

Organs that enable fish to breathe. They consist of filaments connected to the gill arches. The fish's blood is oxygenated in the gills and circulates to the rest of the body.

Gonophore

Anal fin transformed into a reproductive organ.

Grazers

Group of fish that nibble on undersea vegetation or coral.

Habitat

Living space in which a species finds the ecological conditions necessary for it to reside and reproduce.

Harpoon

Iron bar with an arrowhead at one end, often used to hunt sharks, whales, seabream, brown meagre, and other species.

Herbivore

Animal that feeds exclusively on plants.

Heterocercal

Type of tail fin in which the spine curves upward, forming an upper lobe of larger size.

Homocercal

Apparently symmetrical tail fin typical of teleost fish. It is not an extension of the spine.

Ichthyology

Branch of zoology concerned with the study of fish, including their anatomy, physiology, behavior, etc.

Industrial Fishing

Process for catching large quantities of fish from the sea for sale on the international or local market.

Internal Fertilization

Fertilization of cartilaginous fish, aided by the male's copulating organ. These organs, called claspers, developed from modifications of the pelvic fins.

Keel

Ridge or fleshy border along the sides of the caudal peduncle.

Larva

Immature but separate life-form, quite different from the adult.

Lateral Line

Line along the sides of the fish's body consisting of a series of pores.

Luminous Organs

Most fish in the ocean depths have bioluminescent organs that shine in the darkness and are used to attract prey or to communicate.

Lungfish

Fish that appeared in the Mesozoic Era, 250 million years ago. Like amphibians, these species breathe with lungs and are considered living fossils. Only three species have survived to the present.

Lure

Fixed or articulate lures are used in fishing to imitate small fish that are the prey of larger predatory fish.

Mesopelagic

Relating to organisms that live in the ocean depths, where light is dim. The mesopelagic zone is intermediate between the upper or euphotic (well-lit) zone and the lower or aphotic (lightless) zone.

Metamorphosis

Drastic change in the shape and behavior of an animal, usually during growth from an immature phase to maturity.

Migration

Travel (vertically in depth, horizontally toward the coast or along the coast) by schools of fish at more or less regular intervals (daily or seasonally), prompted by factors such as temperature, light, feeding, reproduction, etc.

Mimicry

Ability of certain organisms to modify their appearance to resemble elements of their habitat or other, better protected species, using camouflage to hide from their predators or prey.

Mouth Incubation

Mode of gestation for certain fish species that incubate the eggs inside their mouth and spit them into a burrow to feed. When the eggs hatch, the parent protects the young inside its mouth.

Multispecific Fishing

The harvesting of many species of fish and shellfish, with no particular species considered more important than the rest. This type of fishing is done in tropical and subtropical waters.

Oceanic

Region of open water beyond the edge of the continental shelf or island coasts.

Operculum

Gill cover of bony fish.

Osteichthyes

Class of fish that includes all bony fish, characterized by a highly ossified skeleton. This is contrasted with the class Chondrichthyes, including fish with cartilaginous skeletons (rays, skates, chimaeras, and sharks).

Ovoviviparous

Describing prenatal development of the young within the egg capsule, which is stored inside the female's body.

Parasite

Organism that feeds on organic substances of another living being or host, with which it lives in temporary or permanent contact, either within the host's body (endoparasite) or outside of the host's body (ectoparasite). Such an organism can cause sickness in the host.

Pectoral Fin

Paired fins located in the thoracic region, behind the gill openings.

Peduncle

Structure that acts as a support. In fish, it is a part of the fish's body located between the tail fin and the anal fin.

Pelagic

Relating to organisms that live at or near the ocean's surface.

Photophore

Mucous glands modified for the production of light. The light can come from symbiotic phosphorescent bacteria or from oxidation processes within the tissues.

Phytoplankton

Microscopic plants, of great importance as the basic link in most underwater food chains.

Placoid

Scales typical of cartilaginous fish and other ancient species. These scales are made of pulp, dentine, and enamel like that found in teeth, and they have a small protrusion. They are usually very small and point outward.

Plankton

Group of floating aquatic microorganisms, passively moved by winds, currents, and waves.

Port

Area along the coast, sheltered by natural or artificial means, where ships dock and carry on their operations.

Predator

Species that captures other species to feed on them.

Ray

In fish, bony structures that support the fins.

Reef

Hard bank that barely reaches above the ocean surface or that lies in very shallow waters. It can pose a danger for navigation. It can be inorganic in nature or result from the growth of coral.

Sarcopterygii

Another name for the Choanichthyes, a subclass of bony fish. Their fins are joined to the body by fleshy lobes, and those of the lungfish resemble filaments.

Scales

Small bony plates that grow from the skin and overlap each other.

School

Transient grouping of fish of the same population or species, brought together by similar behavior.

Shipyard

Place where small and large watercraft are built and repaired.

Simple Metamorphosis

Process in which the general appearance of an animal remains similar, although some organs atrophy and others develop.

Spawning

Action of producing or laying eggs.

Spines

Bony rays that support certain fins.

Spiracle

Gill openings between the jaw and hyoid arch. These are highly developed in fish of the class Chondryichthes and in a few groups of primitive fish. Their main function is to eliminate excess water optimizing water flow into the gill slits. Spiracles are especially important to rays when on the seafloor because the spiracle is where the water enters their gills.

Spoon

In fishing, a metallic lure trimmed with hooks. As the fisher reels in the line, the sinker bobs in the water like a dying fish to attract a larger fish and tempt it to bite the bait.

Sportfishing

Sport of catching fish by hand. In most cases the fish, once caught, is returned to the sea or river.

Stinger

Sharp point that grows from the skin. The order Rajiformes includes two families that have poisonous stingers on the final one third of their tail. The stinger is extremely sharp and has serrated edges.

Sucker

Structure formed from the pectoral and pelvic fins to generate pressure and stick to a surface. It can also be a modification of the anterior dorsal fin, the pelvic fin, or the buccal (mouth) disk of the cyclostomes.

Swim Bladder

A sac located in the anterior dorsal region of the intestine that contains gas. Its function is to enable the animal to maintain buoyancy. This structure evolved as a lung, and, in some fish, it retains its breathing function.

Symbiosis

Biological partnership established between two or more individuals (plants or animals) to obtain mutual benefits.

Tetrapod

Animal with two pairs of limbs, each of which ends in five fingers or toes.

Ventral Fin

Paired fins located on the abdomen.

Zooplankton

Microscopic larvae of crustaceans, fish, and other sea animals.

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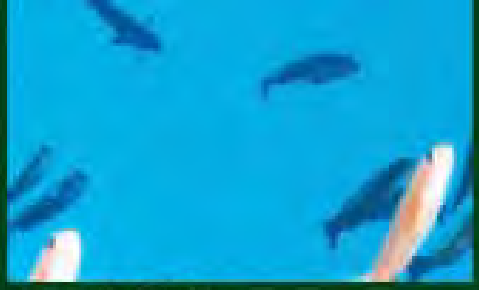

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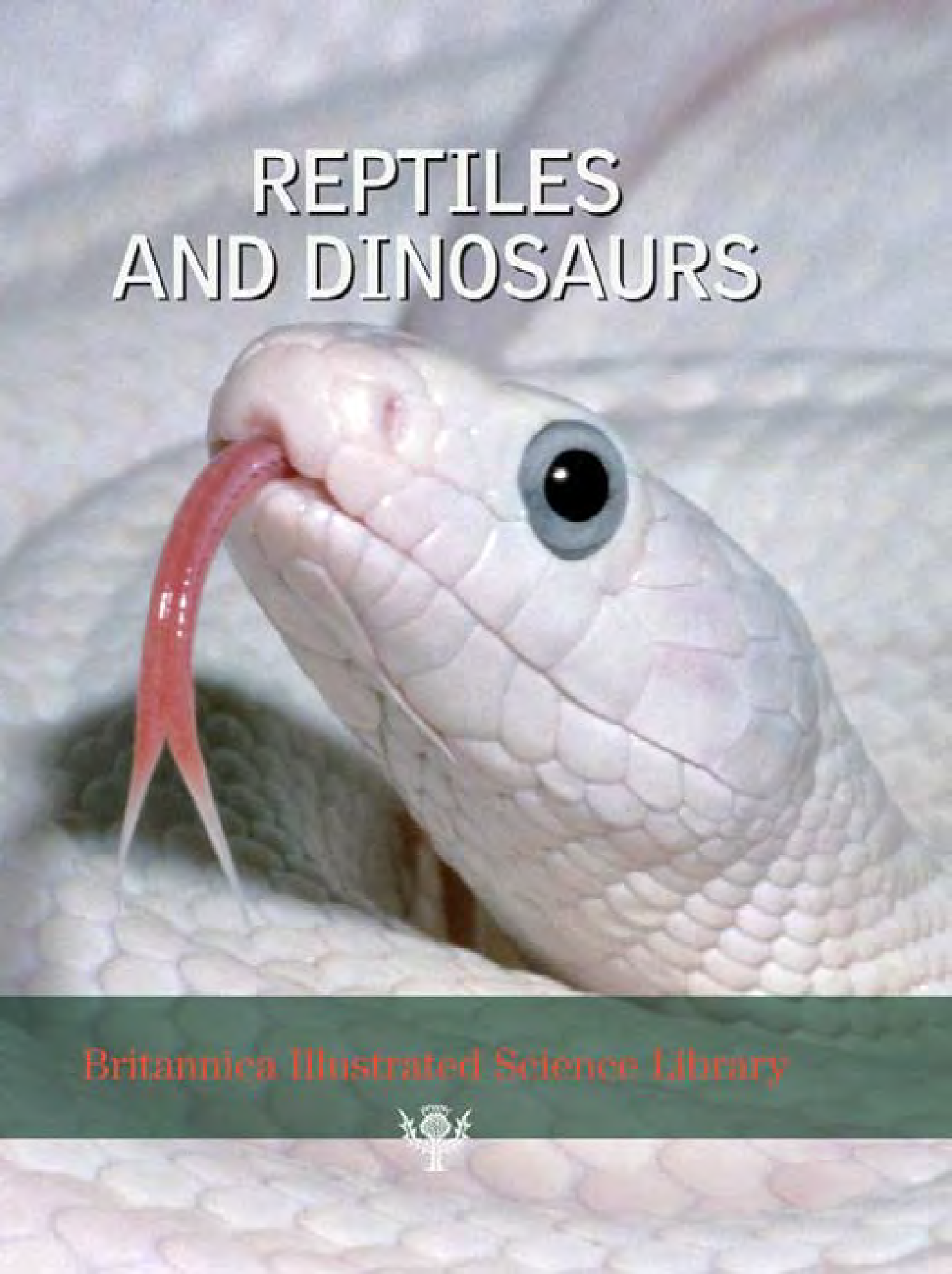
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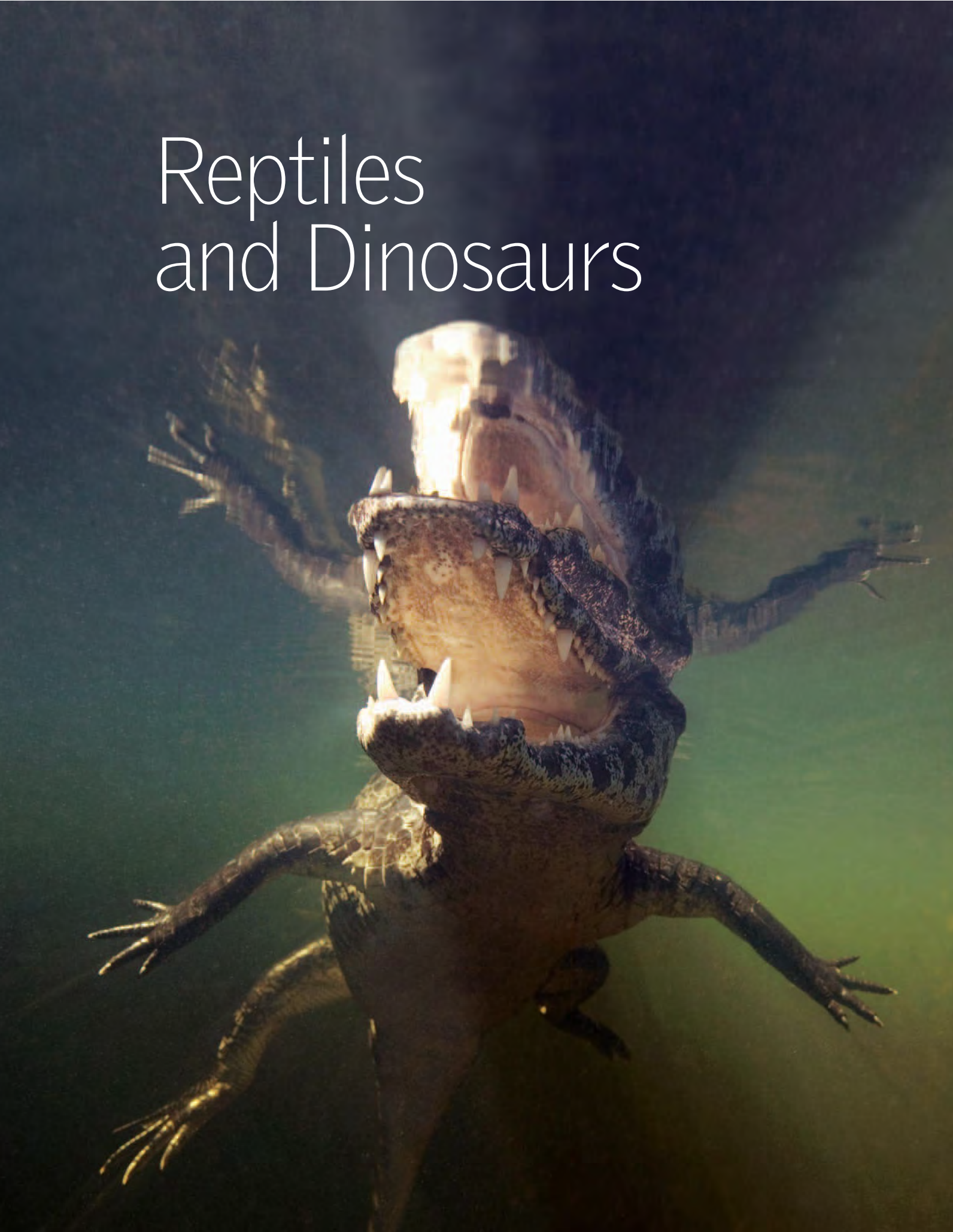

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PHOTOGRAPH ON PAGE 1
The caiman, an inhabitant of South and Central America, is a reptile that lives mostly on crustaceans, insects, and invertebrates.

NAGA RASSA MASK
This mask is used during popular festivals in Sri Lanka to frighten evil spirits. In Asian cultures, nagas represent sacred serpents.

Feared and Worshipped

Because of their frightening appearances, snakes, dragons, and crocodiles are found in the legends and myths of peoples throughout the world. In sculptures, paintings, and masks used for various ceremonies, many of these animals are represented as good or bad gods or are associated with magical powers. The snake is usually linked to the primordial waters from which life was created. In Asia, it is said that nagas (sacred serpents) are descended from Kasyapa, the father of all life. Consequently, it is common during popular festivals for both men and women to dance disguised with masks that represent these animals in order to frighten away evil spirits and seek protection. Certain Papuan peoples believe that crocodiles have special powers, and in Europe, mythical winged dragons that breathe fire are viewed as the guardians of treasures. Throughout history, these animals have been both feared and respected, objects of fascination and passion. The purpose of this book is to reveal, in detail, what reptiles are really like. Here you will find clear, precise information about the appearance and behavior of reptiles, including dinosaurs—a group of reptiles that dominated the globe for millions of years. This fascinating book, which features specially prepared illustrations and images, will reveal details about these creatures as if they were alive on these pages.

Did you know that reptiles were the first vertebrates to become totally independent of aquatic environments? This was made possible by the emergence of the amniotic egg. Its shell and membranes enabled reptilian young to develop on land without the need to return to water. Today there are about 8,200 classified species of reptiles in a wide variety of shapes and sizes. These species include turtles, lizards, snakes, crocodiles, and tuataras. Clues about the lives of many of these animals can be found by examining their feet. Different species use their feet to scale walls, climb slender stalks, or run across loose, hot sand dunes. Some reptiles live underground, while others prefer the surface. Since their body temperature is variable, reptiles tend to spend many hours in the sun exposed to direct solar rays and infrared radiation released from heated surfaces.

With their long, narrow bodies, snakes are different from all other reptiles because they have long spines with many vertebrae. Although they cannot hear in the way mammals do, they can detect low-frequency vibrations in the soil that reveal the presence of predators or prey. Most snakes are carnivorous and can eat objects larger than their own bodies. Stealthy, undulating crawling, sudden color changes, and oversized jaws are other identifying characteristics of reptiles—amazing animals with extraordinary traits that have enabled them to survive for millions of years.

Each page of this book will help you to become familiar with these creatures that are so different from humans. Some of them give birth to completely developed young. They are not born fragile and immature, dependent on their parents to feed and take care of them, as most mammals are. Reptile species also vary widely in the types of scales they have. Their scales may have defensive knobs and spines, as is the case with the tails of some lizards, or they may form crests along their necks, backs, or tails.

Although snakes are some of the most commonly feared animals, only one out of ten is dangerous. Few people know that snakes are timid creatures that prefer to stay hidden. Most snakes will never attack unless they feel threatened and use warning mechanisms and behaviors before attacking. Unfortunately, others are poisonous—so most snakes are hated and persecuted. The process of learning more about them and learning to identify the really dangerous ones may help us to keep them from disappearing. Many reptile species today are in danger of extinction because of indiscriminate hunting and habitat destruction. Not only ecologists but all people must be concerned about their welfare, helping to ensure that they continue to be part of life on Earth.

Dinosaurs

PTERODACTYL
Fossils of this flying dinosaur are found in rocks from the late Jurassic and Cretaceous periods.

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LIVING LIFE TO THE LIMIT 28-29

During the 170 million years from the late Triassic Period to the late Cretaceous Period, an extraordinary group of animals, called the dinosaurs, dominated the Earth. Some were small, but others were gigantic. Some ate only plants and had long necks, and others had sharp teeth. Currently we are increasingly well-informed about dinosaurs because of the findings of paleontologists, who study the fossilized teeth and bones of these animals. Sometime during the late Cretaceous Period, dinosaurs disappeared from the face of the planet in an event known as the K-T extinction event. Some attribute the dinosaurs' disappearance to the impact of a large meteorite with the Earth. In this chapter, you will find very detailed illustrations of these prehistoric creatures.

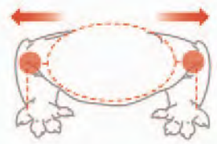
Terrible Lizards

Dinosaurs dominated the Earth for 170 million years, from the late Triassic to the late Cretaceous periods, when the supercontinents of Laurasia and Gondwana were splitting into the landmasses of today. The mass extinction of the dinosaurs about 65 million years ago left fossil remains, including footprints, eggs, and bones. Finding these fossils has enabled scientists to study and classify dinosaurs and to learn about their posture, size, diet, and many other aspects of their lives. These studies revealed that this prehistoric group of lizards included herbivores and carnivores of extraordinary size and striking shapes.

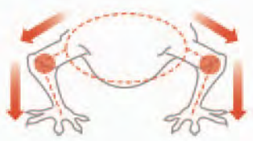
Legs

Depending on their lifestyle, some dinosaurs walked on two legs, and some walked on four. However, they all had a similar posture. Due to the structure of their legs, they bear little resemblance to their relatives today: lizards, tuataras, turtles, snakes, and crocodiles.

1 LIZARDS
The limbs project outward. At the elbows and knees, the legs are bent at right angles. This arrangement is called extended posture.



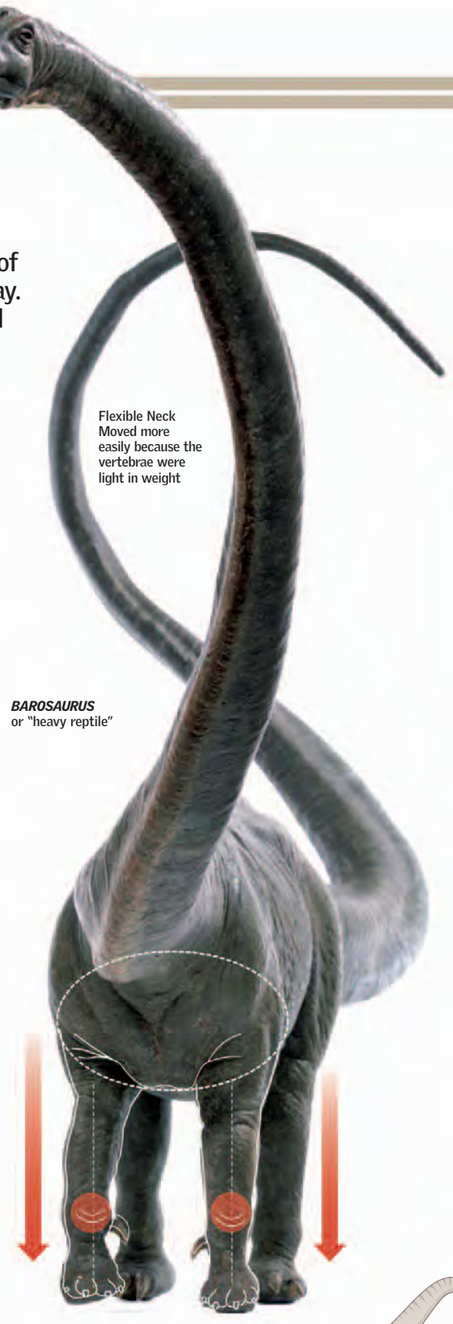
2 CROCODILES
These animals have semi-extended posture. The limbs project out and down. The elbows and knees are bent at a 45° angle. These species crawl slowly and straighten up to run.



DEINOS Terrible **SAURO** Lizard

IDENTITY
The term Dinosauria was proposed for these extinct reptiles by paleontologist Richard Owen in 1842. The name of each species is based on characteristics of its shape and physiology, the name of its discoverer, or the location where it was found.

3 DINOSAURS
These animals had erect posture. The limbs project below the body. Both the elbows and the knees are beneath the body.



BAROSAURUS
or "heavy reptile"

Flexible Neck
Moved more easily because the vertebrae were light in weight

Marsh vs. Cope

The American paleontologists Othniel C. Marsh and Edward D. Cope faced off in a very peculiar struggle. They competed to determine who could find more dinosaur bones and species. The competition was plagued with corruption, mutual accusations of espionage, fraud, theft, and even personal violence. Marsh considered himself the winner of "Bone Wars," but the field of paleontology was the real winner as roughly 130 species were identified between the two rivals.

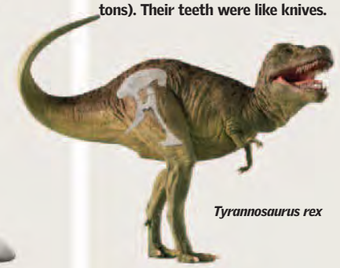
SIR DINOSAUR
Sir Richard Owen, a British paleontologist, was the first to identify fossil remains of "terrible lizards," or "monstrous lizards." He proposed the term Dinosauria, based on his studies and discoveries, and made the first reconstruction of a fossil for the great London Exhibition of 1851.

Saurischians

These dinosaurs had hip bones similar to those of today's reptiles, such as crocodiles and lizards. Many species of saurischian dinosaurs have been found, including *Velociraptor* and *Argentinosaurus*. They had long, flexible necks and large claws on the initial digits.

Lizard Hip
Pelvic structure of saurischian dinosaurs

FIERCE LIZARDS
Carnivores of the Cretaceous Period. They grew up to 46 feet (14 m) long and weighed up to 7.7 tons (7 metric tons). Their teeth were like knives.



Tyrannosaurus rex

SUBORDER	INFRAORDER
Theropoda	Ceratosauria *Coelophysis bauri*
	Tetanurae *Allosaurus fragilis*
Sauropodomorpha	Prosauropoda *Plateosaurus engelhardti*
	Sauropoda *Argentinosaurus huinculensis*

Ornithischians

Herbivores with hip bones structured like those of birds. The pubis slants backward, parallel to the ischium. Some of the most famous ornithischians were *Triceratops* and *Parasaurolophus*. Some ornithischians were protected from head to tail by bony plates.

They Only Look Alike
In spite of their name, these animals are not ancestors of today's birds.

ORNITHISCHIANS
Named for the curvature in their thighbones. They could walk on two legs.

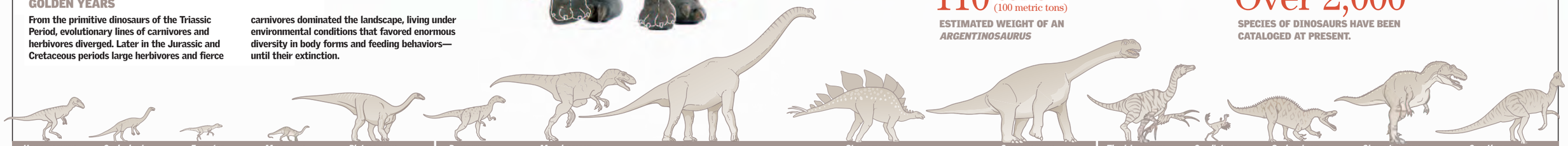
Camptosaurus sp.

SUBORDER	INFRAORDER
Thyreophora	Scelidosauria *Trimucrodon cuneatus*
	Stegosauria *Stegosaurus armatus*
	Ankylosauria *Centrosaurus* sp.
Cerapoda	Marginocephalia *Triceratops prorsus*
	Euornithopoda *Pisanosaurus mertii*

GOLDEN YEARS
From the primitive dinosaurs of the Triassic Period, evolutionary lines of carnivores and herbivores diverged. Later in the Jurassic and Cretaceous periods large herbivores and fierce carnivores dominated the landscape, living under environmental conditions that favored enormous diversity in body forms and feeding behaviors—until their extinction.

110 tons (100 metric tons)
ESTIMATED WEIGHT OF AN *ARGENTINOSAURUS*

Over 2,000
SPECIES OF DINOSAURS HAVE BEEN CATALOGED AT PRESENT.



Herrerasaurus Length: 13 feet (4 m)
Coelophysis Length: 9.2 feet (2.8 m)
Eoraptor Length: 3 feet (1 m)
Mussaurus Length: 6.6 feet (2 m)
Plateosaurus Length: 26 feet (8 m)
Dryosaurus Length: 13 feet (4 m)
Megalosaurus Length: 29.5 feet (9 m)
Brachiosaurus Length: 82 feet (25 m)
Stegosaurus Length: 30 feet (9 m)
Camarasaurus Length: 66 feet (20 m)
Therizinosaurus Length: 39 feet (12 m)
Caudipteryx Length: 3 feet (1 m)
Suchomimus Length: 43 feet (13 m)
Giganotosaurus Length: 49 feet (15 m)
Corythosaurus Length: 33 feet (10 m)

TRIASSIC PERIOD 251-199.6 MILLION YEARS AGO
JURASSIC PERIOD 199.6-145.5 MILLION YEARS AGO
CRETACEOUS PERIOD 145.5-65.5 MILLION YEARS AGO

The Triassic Period

The biological crisis of the late Permian Period was followed by a slow resurgence of life in the Triassic Period. The Mesozoic Era has commonly been called the "Age of Reptiles," and its most famous members are the dinosaurs. In the earliest part of the period, the first representatives of today's amphibians appeared, and toward the end of the period the first mammals emerged. In the middle to late Triassic Period, the many families of ferns and conifers appeared that continue to exist today, as well as other groups of plants that are now extinct.

THE TRIAS
were named in 1834 by German paleontologist Friedrich August von Alberti, who in doing so grouped the three rock formations that defined this period.

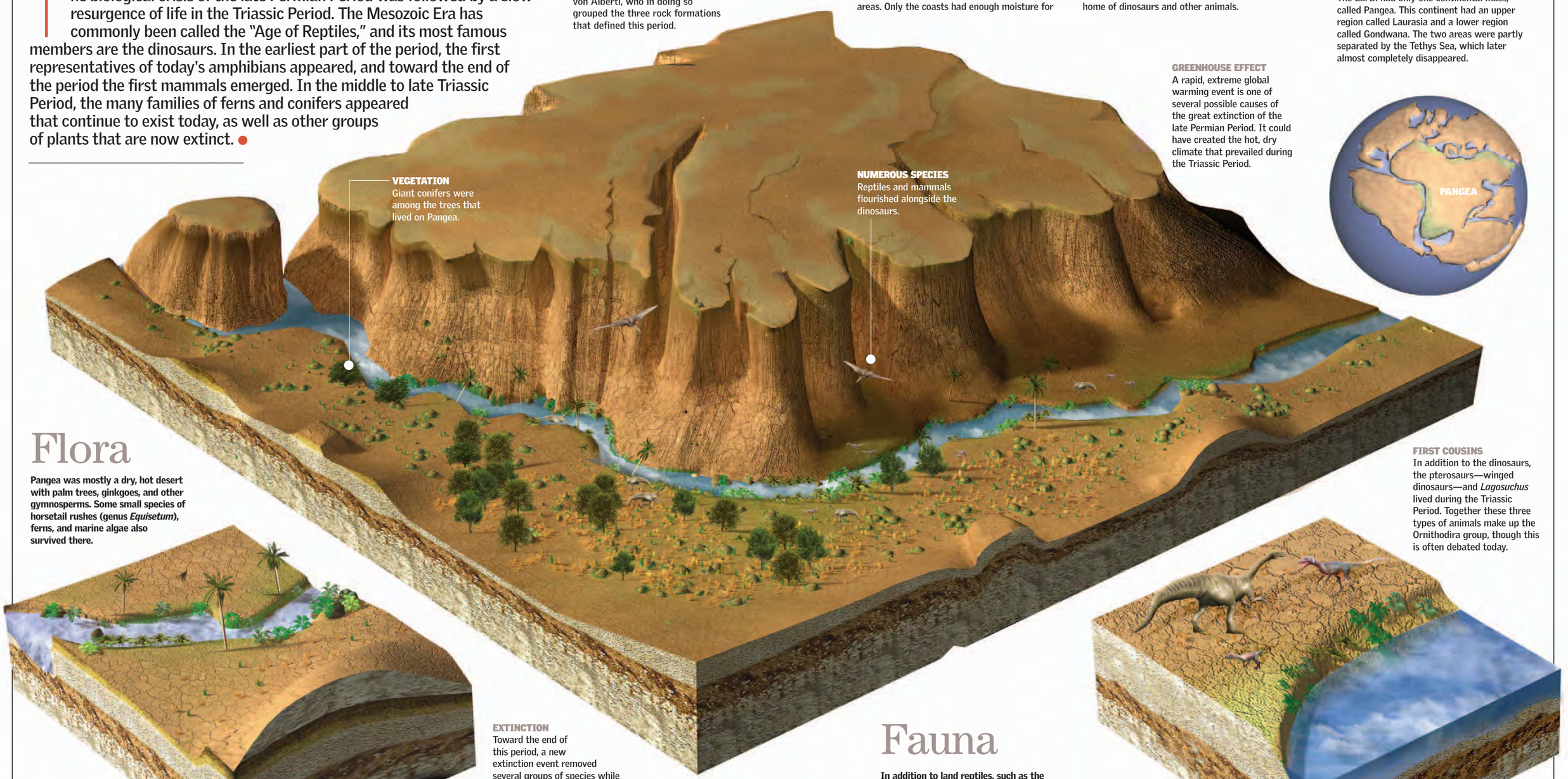
A New World

After the extinction of nearly 95 percent of all life at the end of the Permian Period, the Earth was a dry place with hot deserts and rocky areas. Only the coasts had enough moisture for plants to grow. There was only one continent, called Pangea, which was surrounded by a single ocean, Panthalassa. This supercontinent was the home of dinosaurs and other animals.

GREENHOUSE EFFECT
A rapid, extreme global warming event is one of several possible causes of the great extinction of the late Permian Period. It could have created the hot, dry climate that prevailed during the Triassic Period.

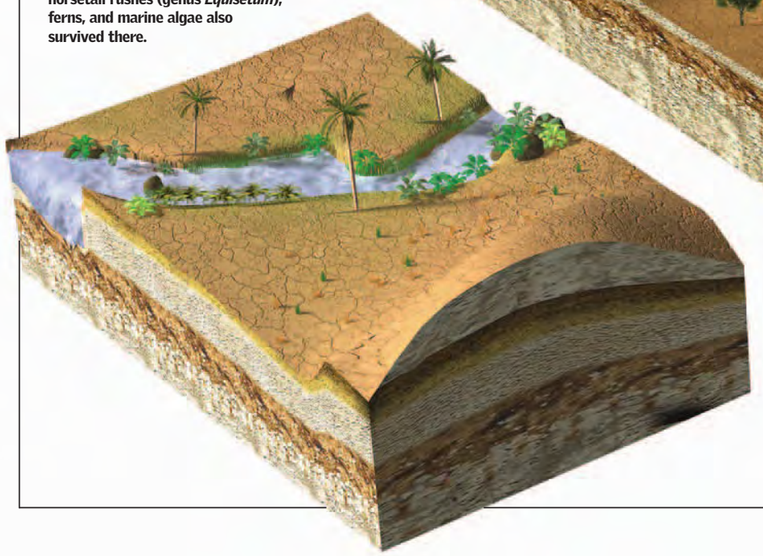
250 TO 203 MILLION YEARS AGO

The Earth had only one continental mass, called Pangea. This continent had an upper region called Laurasia and a lower region called Gondwana. The two areas were partly separated by the Tethys Sea, which later almost completely disappeared.



Flora

Pangea was mostly a dry, hot desert with palm trees, ginkgoes, and other gymnosperms. Some small species of horsetail rushes (genus *Equisetum*), ferns, and marine algae also survived there.

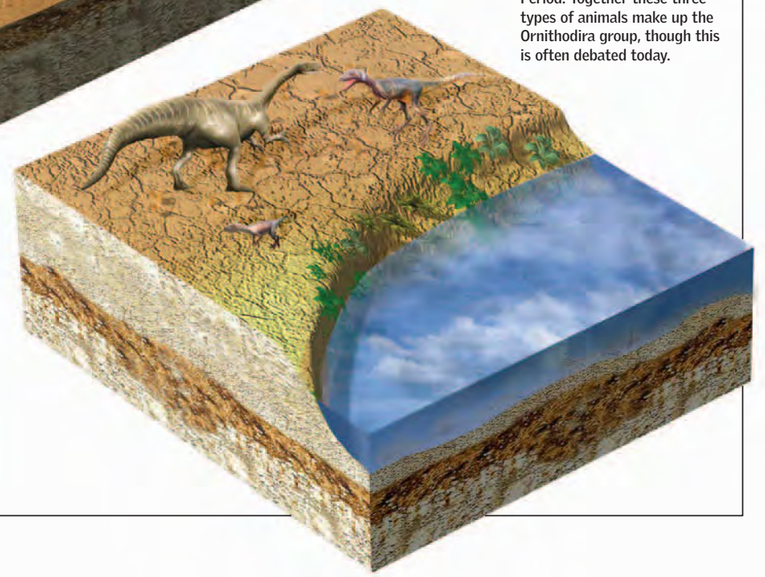


EXTINCTION
Toward the end of this period, a new extinction event removed several groups of species while opening up new horizons for those that survived—especially the dinosaurs, which spread rapidly.

Fauna

In addition to land reptiles, such as the crocodile, and the most primitive dinosaurs, such as *Eoraptor*, the first mammals appeared during this period.

FIRST COUSINS
In addition to the dinosaurs, the pterosaurs—winged dinosaurs—and *Lagosuchus* lived during the Triassic Period. Together these three types of animals make up the Ornithodira group, though this is often debated today.



The "Age of Reptiles"

The first period of the Mesozoic Era gave rise to the "Age of Reptiles." On land, the synapsids, which later developed into mammals, began to decline, and the archosaurs, or "dominant reptiles," lived in various habitats. The earliest crocodiles began to develop, along with turtles and frogs, among others. The pterosaurs ruled the air and the ichthyosaurs the water. The dinosaurs—another order of archosaurs—appeared in the Middle Triassic, approximately 250 million years ago. Toward the end of the Triassic Period, many other reptiles declined dramatically, and the dinosaurs began their reign.

The First Dinosaurs

The most primitive dinosaurs were very small in comparison to their relatives of later epochs. Most of them have been found in South America. They were carnivores. Some were scavengers, and others were highly agile hunters. They shared very primitive morphological structures with other reptiles of their group, the archosaurs. Mixed with these primitive structures, however, were advanced bone forms similar to those of the predators that would dominate the Cretaceous Period. These predators were known as the theropods. Throughout the Triassic Period, the early dinosaurs were an uncommon subgroup of reptiles. Toward the end of the Triassic Period, the first large herbivores appeared.

Eoraptor

Eoraptor fossils were discovered in 1991 in northwestern Argentina. This small carnivore lived 228 million years ago and measured up to 40 inches (1 m) long. It had sharp teeth and agile hind legs for running and chasing its prey. It may also have eaten carrion.

EORAPTOR
Tiny predator whose name means "thief of dawn"

HOLLOW SHAPE
is what *Coelophysis* means.

Coelophysis

This skilled carnivore could grow up to 9.2 feet (2.8 m) long. Two types of fossils have been found. They are believed to be males and females, respectively. Fossils of this biped hunter have been found in the United States in several southwestern states.

Mussaurus

The only known fossils of this species were found alongside eggshells. They were no more than 8 inches (20 cm) long. Their adult size is unknown, but it is estimated to have been as much as 6.5 to 8 feet (2-2.5 m). They are known to have been herbivores.

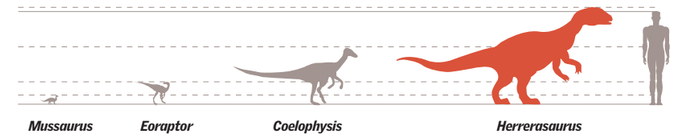
MUSSAURUS
means "rat reptile."

HERRERASAURUS

Herrerasaurus ischigualastensis

Size	13 feet (4 m)
Diet	Carnivorous
Habitat	Conifer Forests
Epoch	Late Triassic
Range	South America

DIFFERENT SIZES



Herrerasaurus

is one of the most ancient dinosaurs. It is considered a key to understanding the path dinosaurs took to dominate the following 160 million years. The first fossils were found in the early 1960s in the Ischigualasto valley in northern Argentina by an official paleontological commission headed by Osvaldo Reig. He named the dinosaur in honor of the local guide who found it. Since then several complete skeletons have been found.

A TRUE CARNIVORE
One of the traits that defined this animal as a dinosaur was its typical theropodian head. Its narrow skull had nasal cavities in the front part of its snout, and its eye sockets were part of a hollow bony structure, making its skull both lightweight and strong.

MOUTH
Its tubelike teeth were more curved than those of other carnivores that followed, but they were sharp and serrated like those of its theropod relatives.

LIMBS FOR HUNTING
Like its head, this dinosaur's limbs had the same proportions as the later giant predators of the Cretaceous Period. Its small front limbs were designed for capturing prey.

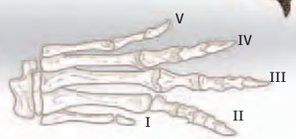
TAIL
Most predators used their tails to keep their balance while chasing their prey.

SPINAL COLUMN
The central vertebrae are high and short, and the neural arches have square-shaped projections that are thicker toward the back. There are only two sacral vertebrae.

PELVIS
Herrerasaurus was a very early saurischian with a primitive sacrum, ilium, and hind legs but a highly developed pubic bone and vertebrae. These traits show that this dinosaur had unique characteristics in its spinal column.

FRONT LIMBS
The relative size of its front limbs suggests that this animal mainly walked on two feet. Each hand had three long claws and two short ones. Its hands were able to grasp with the help of "thumbs" slightly opposed to the other claws. Its hand was a formidable weapon for attacking and holding prey, an earlier form of the hands of other theropods.

HIND LEGS
On its lower limbs, this dinosaur's toe bones show a high degree of superposition. The toe bones of the first digit, although well developed, are very short and lightweight compared to the second, third, and fourth toes. These long, strong feet enabled *Herrerasaurus* to run while bearing the great weight of its body.



220 pounds (100 kg)
An adult *Herrerasaurus* weighed between 220 and 880 pounds (100-400 kg).

The First Giant Herbivore

This primitive saurischian was among the first to usher in the age of the dinosaurs in the late Triassic Period, about 210 million years ago. Dinosaurs had already been in existence for some time, but they were smaller predators thus far. The saurischian was clearly one of the first that fed exclusively on plants and that reached the immense sizes typical of herbivores. Many fossils have been found in over 50 separate locations. The secret of this dinosaur's survival is believed to have been the lack of competition for food, since no other herbivore of the time grew as large. Its name, which means "lizard-hipped," was given to it in 1837 by the German naturalist Hermann von Meyer.

Plateosaurus engelhardti

These prosauropods, of the suborder Sauropodomorpha, were among the primitive herbivorous dinosaurs that were forerunners of the giant sauropods of the Jurassic Period. However, they were not actually ancestors of these animals. It is known that they associated with others of their own species because, in many areas, several specimens have been found together. Because of the hot, dry conditions that prevailed where they lived, it seems that they migrated constantly in search of food, which consisted of conifers and palm trees.

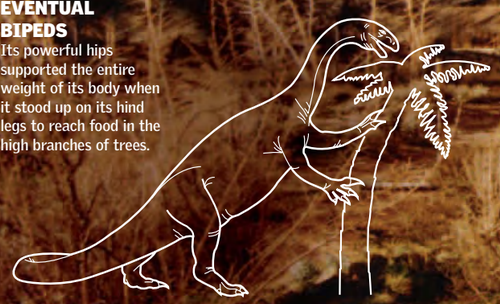
SEXUAL DIMORPHISM
It is thought that *Plateosaurus* varied in size according to its environment. There is also evidence that males and females had different shapes.

Head
Its brain was small in proportion to the weight of its body, so it is not believed to have been very intelligent.

In the Treetops
Its long neck helped it to reach the tops of trees. Its mouth had pouches for storing food while it chewed.

Movement
It moved about on its four muscular legs, but it could probably stand up on its hind legs and run quickly.

EVENTUAL BIPEDS
Its powerful hips supported the entire weight of its body when it stood up on its hind legs to reach food in the high branches of trees.



WEIGHT-BEARING TOES

Defensive Claw
This animal had few defensive resources. However, one of the toes of its front feet had a powerful claw that it used to cut branches and for self-defense. In reality, however, its best defense was to run.

MATING
Plateosaurs were polyandrous, meaning that the dominant matriarch had from three to five male mates, who competed for her attention during mating season. The eggs, of various sizes, were cared for by each respective male.

PLATEOSAURUS

Plateosaurus engelhardti

Size	**26-33 feet** (8-10 m)
Diet	**Herbivorous**
Habitat	**Semiarid Regions**
Epoch	**Late Triassic**
Range	**Europe**

WHERE IT LIVED
Its fossils were found in semiarid areas of what are now Germany, France, and Switzerland. At the time, those areas were part of the supercontinent Pangea.

The Jurassic Period

During this period, dinosaurs diversified greatly and spread out to occupy land, sea, and air. Along with large herbivores, there were salamanders, lizards, and the *Archaeopteryx*, the most ancient bird known. The climate of the Jurassic Period was mild, with moisture-laden winds from the ocean. They brought great downpours, enabling forests to cover wide areas of land.

STUDIES IN JURA
The name "Jurassic" comes from the Jura mountain range in the northern Swiss Alps. This is where the formal mapping of the rocks of this period took place.

The Green Planet

As Pangea split apart, the sea level rose, and large areas of land were flooded. This process increased humidity levels, which led to intense rainfall and created a milder climate. These climate conditions helped create rich forest ecosystems. Afforded abundant food, animal populations skyrocketed. The splitting of the continent also caused volcanic eruptions. Despite the dramatic movements of tectonic plates, the climate was warm and temperate on most areas of the planet.

A NEW OCEAN
The Tethys Sea expanded from east to west, separating Laurasia and Gondwana. The Gulf of Mexico and the Atlantic Ocean began to form.

208 TO 140
MILLION YEARS AGO

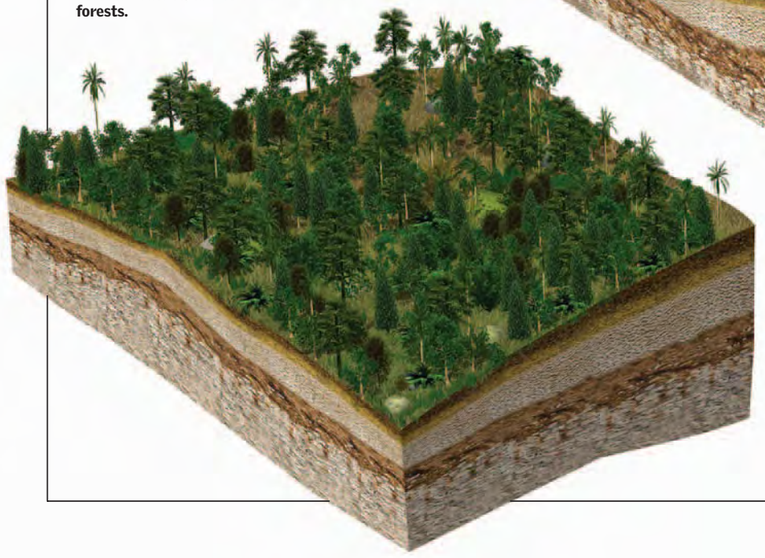
The Earth began to divide. During the Jurassic Period, North America drifted north and separated from what is now South America. North America formed part of Laurasia with what would become Europe. Antarctica, South America, India, and Australia formed Gondwana to the south.

PLANT LIFE GROWS
Trees began to cover regions that had once been deserts.

ORNITHISCHIANS
These dinosaurs were numerous on the continents.

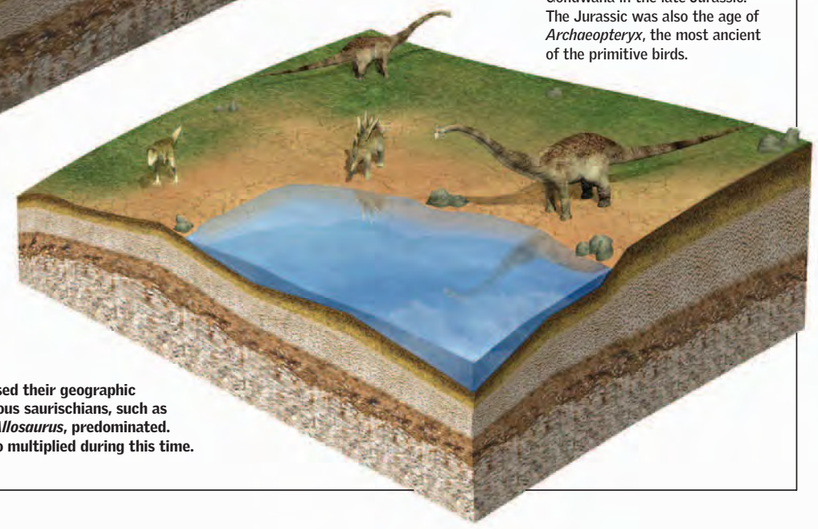
Flora

Because of increasing rains, plant life became lush and exuberant. Mosses grew in the seas and on land. Many species of conifers, horsetail rushes, and ferns formed dense forests.



COAL
Abundant coal beds dating back to this period proved good indications of the high humidity and abundant vegetation of the time.

SHARED WORLD
During this period, the first marsupials appeared. Today highly developed versions of these mammals exist in Australia, which split apart from the rest of Gondwana in the late Jurassic. The Jurassic was also the age of *Archaeopteryx*, the most ancient of the primitive birds.



Fauna

Dinosaurs greatly diversified and increased their geographic distribution during this period. Herbivorous saurischians, such as *Brachiosaurus*, and carnivores, such as *Allosaurus*, predominated. Ornithischians, such as *Stegosaurus*, also multiplied during this time.

Different Species

During the middle of the Jurassic Period, the planet was lush and green. The gradual splitting of Pangea created new ecological environments, which were more humid and more diverse. The increased humidity enabled the growth of large trees and dense vegetation. This flourishing environment powered the continued diversification of different dinosaur species. In contrast, these conditions forced a decline in the majority of synapsids, and the archosaurs —the group that includes crocodiles— largely disappeared. Other species also found their ecological niches and multiplied. These species included sea creatures, such as sharks and rays, that resemble their modern relatives, as well as ray-finned fish with sharp teeth, such as the fierce predator *Aspidorhynchus*.

Giants of the Mesozoic

Giant herbivores dominated the Earth. However, increasing diversity also brought increasing competition. The large sauropods, such as *Diplodocus*, and ornithischians, such as the stegosaurids, had to watch out for larger theropods, such as *Megalosaurus*, as well as for hordes of small, swift predators, such as *Compsognathus*. The first bird to descend from small dinosaurs appeared.

DRYOSAURUS
means "oak reptile."

MEGALOSAURUS
means "large lizard."

Megalosaurus

In 1676, the bones of one of the first dinosaurs were found in southern England, although they were not identified as such until 1819. This theropod predator was highly intelligent in comparison to its peers. It lived 181 million years ago, grew up to 29.5 feet (9 m) long, and weighed 1.1 tons (1 metric ton). It walked on its two hind legs and had two powerful front claws.

Dryosaurus

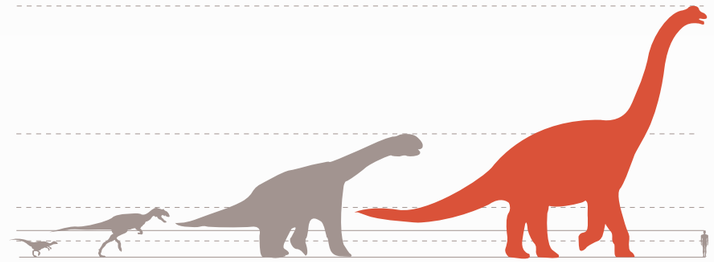
The fossils of this ornithopod, of the suborder Ornithischia, were found in Tanzania and the United States at the same time during the 19th century, in the middle of the so-called "Bone Wars." This lightweight herbivore could reach up to 14.8 feet (4.5 m) long and weigh nearly 200 pounds (90 kg).

CAMARASAURUS
means "chambered lizard."

Camarasaurus

This large, herbivorous sauropod lived on the plains of North America 159 million years ago. Its fossils were first found in 1877. It grew up to 65.5 feet (20 m) long; even so, it was easy prey for large predators such as Allosaurus. It could weigh up to 22 tons (20 metric tons), and it walked on four feet, which prevented it from running quickly enough to easily escape.

COMPARATIVE SCALE



Dryosaurus *Megalosaurus* *Camarasaurus* *Brachiosaurus*

BRACHIOSAURUS

Brachiosaurus

Size	**82 feet** (25 m)
Diet	**Herbivorous**
Habitat	**Tree-lined Savannas**
Epoch	**Late Jurassic**
Range	**North America**

Brachiosaurus

For a long time, this sauropod was the largest dinosaur for which we had a complete skeleton. It was a four-footed herbivore with a small brain and a long neck. Specimens have been found in the United States, on the Iberian Peninsula, and in northern and southern Africa. The African species were from the Cretaceous Period and had slight anatomical differences.

HEAD
Its head was small and had a crest between the eyes. This crest had large nasal cavities at the top. Its teeth were like pegs and had spaces between them.

NECK
The length of its neck, in proportion to the rest of its body, sets it apart from other sauropods of its time. By means of its neck, which could be up to 42.5 feet (13 m) long, it could reach the tops of trees.

42.6 feet (13 m)
Height of *Brachiosaurus*, because of its long front legs and long neck

Eye Sockets
Its eyes sat in large sockets.

Nasal Cavities
They are believed to have been resonance chambers.

Jugal (Yoke) Bone
was located behind the upper jaw and under the eye.

Teeth
were used for tearing off tree branches when the head was pulled backward.

TAIL
Its tail was small in comparison to its body and was an extension of its spinal column.

LEGS
Its front legs were longer than its hind legs.

VERTEBRAE

***Brachiosaurus's* extremely long neck had 13 vertebrae, with deep and complex cavities covered by membranes. It had 11 or 12 vertebrae in its back. Its short tail had about 50 bones, which helped it move easily.**

Support
This area anchored the supporting muscles.

Vertebral Joint
The vertebrae were fused to strengthen the neck.

Hollow Bones
made the neck lighter.

Ease of Movement
was made possible by a ball-and-socket joint.

34.8 inches (88.5 cm)

A Docile Vegetarian

This striking dinosaur is one of the most widely studied in the history of paleontology. The first fossils were discovered by Othniel C. Marsh in 1877 in the American West, during the "Bone Wars." This quadruped herbivore could measure up to 29.5 feet (9 m) long and weigh up to 2.2 tons (2 metric tons). Because of its small head, it has been used since the 19th century as a symbol of stupidity. It was later shown that most dinosaurs had small brains and that *Stegosaurus*'s brain was larger than average.

Stegosaurus

Stegosaurus was an ornithischian dinosaur that belonged to the family Stegosauridae. Its distinctive features included wide plates on its back and four spines, up to 24 inches (60 cm) long, on its tail. The function of these features is still under debate, but it is believed that they served mainly for self-defense.

Stegosaurus was an easy victim for the great predators of its time, such as *Allosaurus*, but it is also believed that it may have been hunted by packs of small predators, such as *Ornitholestes*. It is doubtful that *Stegosaurus* could raise itself up on its hind legs, so it probably fed mostly on low bushes.

STEGOSAURUS

Stegosaurus armatus

Size	29.5 feet (9 m)
Diet	Herbivorous
Habitat	Subtropical Forests
Epoch	Late Jurassic
Range	North America

WHERE IT LIVED

The first fossils were found in Colorado. Other specimens have since been found in India, western Europe, southern Africa, and China.

Head

Its lightweight head had small teeth that were of little use for chewing, so it swallowed plants whole.

Legs

Its front legs were half as long as its hind legs. Each foot had five wide, short toes.

Tail

Stegosaurus's only real defense was likely the four spines on its tail, which it swung back and forth.

PLATES

These triangular bony structures were not very solid, but they had a complex network of veins. The plates were likely used to regulate the animal's body temperature or even for courtship.

The Cretaceous Period

Was an age of expansion. The dinosaurs continued to diversify, and the first snakes appeared. The Earth began to look like the planet we know today. The movement of tectonic plates created folds that came to form some of the mountain ranges of today, such as the Appalachians in North America and the Alps in Europe. At the end of this period, another mass extinction event occurred, probably caused by the impact of a meteorite.

CRETACEOUS
The name is based on the Latin word *creta*, which means stone. The name comes from the layer of limestone found in the rock formations that define this geological system.

An Evolving Planet

During this period of 80 million years, the Earth's climate changed. Its temperate climate, accompanied by snow in the polar regions during the winter, was transformed into a warm, mild climate with noticeably different seasons. The ocean levels rose, currents increased ocean temperatures, and marine fauna multiplied. On land, the first flowering plants (gymnosperms) appeared, and forests of willow, maple, and oak harbored the last large dinosaurs.

ALPINE MOUNTAIN-BUILDING
During this period, Africa and Eurasia drifted closer together. The Tethys Sea narrowed, and the collision of plates formed the Alpine mountain range.

140 TO 65 MILLION YEARS AGO

The Earth began to adopt an appearance similar to that of today. Africa and South America separated from one another, as did North America and Europe. The North and South American plates drifted westward and collided with the Pacific plate, raising both the Rocky Mountains in North America and the Andes in South America.

FORESTS
Oaks and maples predominated in the most humid regions.

FLYING REPTILES
developed very large wingspans toward the end of this period.

MARINE REPTILES
The expanding seas caused an abundance of marine reptiles and other aquatic species, such as mollusks.

Flora

During the early Cretaceous Period, ferns and conifers predominated. Important groups became extinct at the boundary between the Early and Late Cretaceous. These species were replaced in tropical forest environments by flowering plants, which spread to colder and drier areas.

FLOWERS
During this period, the main advancement in the evolution of plants was the appearance of angiosperms, or plants with flowers and fruit.

Fauna

The Cretaceous Period held the greatest diversity of dinosaurs. This epoch is also known for small mammals, insects, and the largest flying reptiles.

A Fierce Era

The Cretaceous Period saw both the splendor and the end of the "Age of Reptiles." It was the longest period of the Mesozoic Era, and for 80 million years, specific types of animal life developed in each region. South America was home to the largest herbivore known, *Argentinosaurus huinculensis*, which lived at the same time as the fearsome theropods. Some species of this period later survived the mass extinction—especially marine invertebrates, such as crustaceans, gastropod mollusks, and advanced ray-finned fish. Small mammals such as *Zalambdalestes* also survived.

The Struggle to Survive

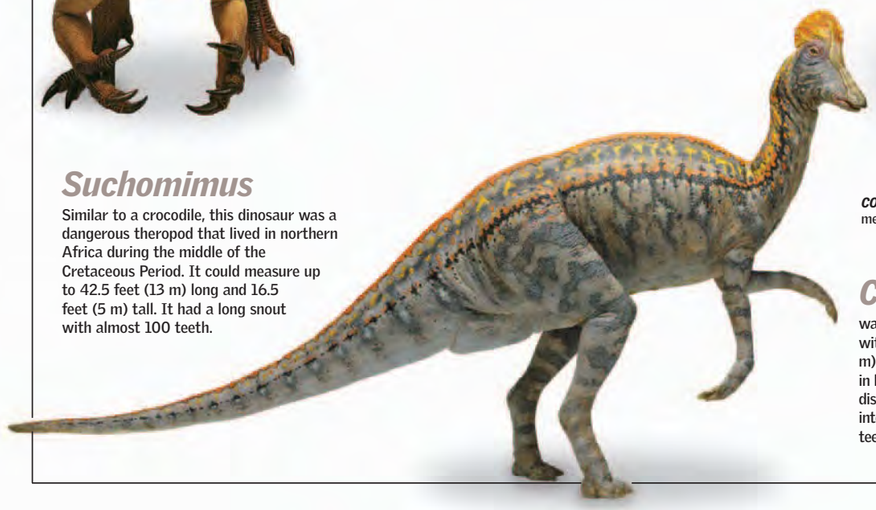
Dinosaurs remained dominant during the Cretaceous Period. Although the large sauropods still existed, new groups emerged, intensifying the competition for resources. Enormous carnivores of the tyrannosaur family in North America and the giganotosaurs in South America were the largest threats to the peaceful herbivores. New, distinctive species, such as the duck-billed hadrosaurs and the armored *Triceratops*, also appeared.

SUCHOMIMUS
means "crocodile imitator."

CAUDIPTERYX
means "tail feather."

Caudipteryx

was a feathered dinosaur that lived in China in the early Cretaceous. It could grow up to 40 inches (1 m) in length and 27.5 inches (70 cm) in height. It was an advanced theropod, but it looked like a large bird, because its arms were covered with feathers and it had an elaborate, fanlike tail. It had claws and a beak with sharp upper teeth. It could reach great speeds when fleeing large predators.



Suchomimus

Similar to a crocodile, this dinosaur was a dangerous theropod that lived in northern Africa during the middle of the Cretaceous Period. It could measure up to 42.5 feet (13 m) long and 16.5 feet (5 m) tall. It had a long snout with almost 100 teeth.

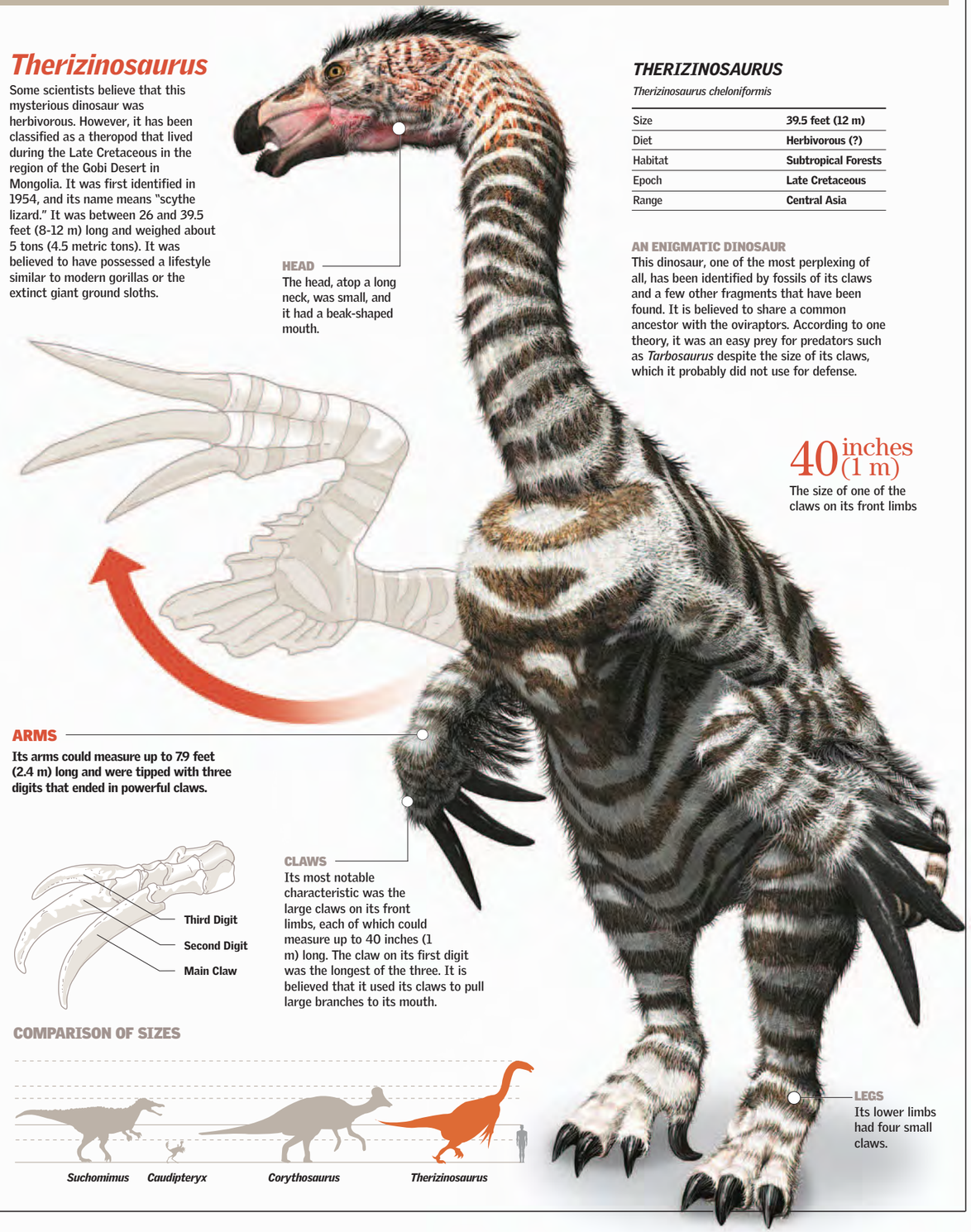
CORYTHOSAURUS
means "helmet lizard."

Corythosaurus

was an ornithischian dinosaur of the hadrosaur family with a showy crest. It could reach up to 33 feet (10 m) long. It ate bushes and fruit in forests, and it lived in herds. The color of its crest may have been a distinctive feature if herds of different species intermingled. Its upper jaw had hundreds of small teeth that were replaced often.

Therizinosaurus

Some scientists believe that this mysterious dinosaur was herbivorous. However, it has been classified as a theropod that lived during the Late Cretaceous in the region of the Gobi Desert in Mongolia. It was first identified in 1954, and its name means "scythe lizard." It was between 26 and 39.5 feet (8-12 m) long and weighed about 5 tons (4.5 metric tons). It was believed to have possessed a lifestyle similar to modern gorillas or the extinct giant ground sloths.



HEAD
The head, atop a long neck, was small, and it had a beak-shaped mouth.

ARMS
Its arms could measure up to 7.9 feet (2.4 m) long and were tipped with three digits that ended in powerful claws.

CLAWS
Its most notable characteristic was the large claws on its front limbs, each of which could measure up to 40 inches (1 m) long. The claw on its first digit was the longest of the three. It is believed that it used its claws to pull large branches to its mouth.

LEGS
Its lower limbs had four small claws.

COMPARISON OF SIZES

THERIZINOSAURUS

Therizinosaurus cheloniformis

Size	**39.5 feet (12 m)**
Diet	**Herbivorous (?)**
Habitat	**Subtropical Forests**
Epoch	**Late Cretaceous**
Range	**Central Asia**

AN ENIGMATIC DINOSAUR
This dinosaur, one of the most perplexing of all, has been identified by fossils of its claws and a few other fragments that have been found. It is believed to share a common ancestor with the oviraptors. According to one theory, it was an easy prey for predators such as *Tarbosaurus* despite the size of its claws, which it probably did not use for defense.

40 inches (1 m)
The size of one of the claws on its front limbs

The Great Predator of the South

The largest carnivorous dinosaur that has ever existed on Earth lived 95 million years ago during the Late Cretaceous Period. Fossils of *Giganotosaurus carolinii* were first found by Rubén Carolini, a mechanic and amateur paleontologist, in 1993. The name means "giant southern lizard." Although only 70 percent of its skeleton was found, it is known that it could reach a length of up to 49 feet (15 m) and that it hunted large sauropods.

Giganotosaurus carolinii

belonged to the order Saurischia, the suborder Theropoda, and the superfamily Allosauridae. It could measure up to 16.5 feet (5 m) in height and weigh 8.8 tons (8 metric tons). The fossilized bones that have been found for this dinosaur include the skull, pelvis, femur, spinal column, and upper limbs. It was thought to hunt in packs, because several fossils have been found together. This made it a deadly threat to the large, herbivorous sauropods of the time.

A New King

For a time, *Tyrannosaurus rex* was considered the largest land predator, although it is now believed by some to have been a scavenger. In 1997, a larger and more fearsome predator was made known to the scientific community. *Giganotosaurus* is considered by some to be the king of the dinosaurs.

GIGANOTOSAURUS
Giganotosaurus carolinii

Size	49 feet (15 m) long
Diet	Carnivorous
Habitat	Forests and Wetlands
Epoch	Late Cretaceous
Range	South America

WHERE IT LIVED

The fossils of this giant predator were found in the province of Neuquén in the region of Patagonia in Argentina.

Powerful Jaws

All predators in the superfamily Allosauridae had powerful jaws and rounded teeth with serrated edges to tear the flesh of their victims. Each tooth could be up to 8 inches (20 cm) long.

1 **Movable Skull**
Its skull slid over its lower jaw so that its knifelike teeth could cut.

2 **Lateral Expansion**
The joints of its skull bones moved outward to better grip its victim.

Large Head

Its head was very large in relation to its body, measuring up to 5.9 feet (1.8 m) long.

Claws

Both the hind legs and the front legs had three toes. The front limbs had sharp claws.

Tail

Filled with solid vertebrae, it was used to maintain balance and could probably swing from side to side.

Swift Hunter

Giganotosaurus's well-developed hind legs enabled it to run at high speed while hunting its prey.

Living Life to the Limit

Extinctions of living beings on Earth have occurred in a series of drastic episodes throughout history, from the Cambrian Period to the Cretaceous. The most famous chapter is associated with the total disappearance of the dinosaurs about 65.5 million years ago. This mass extinction of these large reptiles is so important that it was used by scientists to indicate the end of the Cretaceous Period and the beginning of the Tertiary, a designation known as the K-T boundary ("K" is the abbreviation for Cretaceous). Natural phenomena of terrestrial or extraterrestrial origin are possible causes of the disappearance of these gigantic animals of the Mesozoic Era.

Fatal Meteorites

1 In its long geological history, the Earth has witnessed several mass extinctions. Some scientists argue that the cause could be the same in all cases, and they point to extraterrestrial phenomena as the most likely cause. However, this hypothesis has been widely criticized. From the Paleozoic Era 570 million years ago to the Cretaceous Period, it has been determined that there were five or six mass extinctions on Earth, which mark the boundaries between the following periods: Cambrian-Ordovician, Ordovician-Silurian, Devonian-Carboniferous, and Permian-Cretaceous. However, scientists have yet to determine a convincing factor that could be the cause in all cases. The Devonian extinction exterminated 50 percent of all species, much like the one occurring at the K-T boundary. However, the largest extinction of all occurred in the Permian Period, in which 95 percent of all species were eliminated.

CLUES IN CHICXULUB

In the town of Chicxulub, on the Yucatán Peninsula in Mexico, a depression was found that measured 112 miles (180 km) across. This enormous imprint was evidence of the violent impact of an extremely large meteorite that crashed into the Earth.

POST-EXTINCTION LAYER
Sediments of microfossils from eras later than that of the dinosaurs

FIREBALL LAYER
Dust and ash from the meteorite's impact

EJECTION LAYER
Materials from the crater that settled during several months

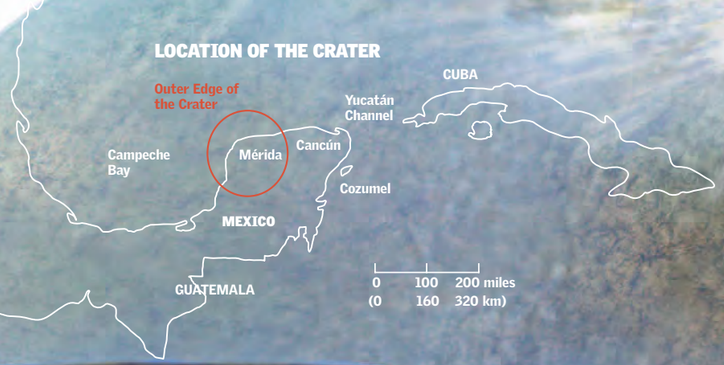
PRE-EXTINCTION LAYER
Sediments with microfossils from the era of the dinosaurs

MIXED ROCKS
Samples taken from the Chicxulub crater show a mixture of terrestrial minerals (dark areas) and meteorite minerals (light areas).

6 miles (10 km)
DIAMETER OF THE ASTEROID that caused the Chicxulub crater in Mexico

50% **OF ALL SPECIES** became extinct at the K-T boundary.

LOCATION OF THE CRATER



112 miles (180 km)
DIAMETER OF THE CHICXULUB CRATER on the Yucatán Peninsula

Other Proposed Theories

Not all scientists agree with the idea that a large meteorite caused the mass extinction of the dinosaurs. Rather, they suggest that the Chicxulub crater was formed 300,000 years before the end of the Cretaceous Period. These scientists claim that terrestrial events, such as volcanic eruptions, were more likely to have caused the Cretaceous extinction. According to intermediate positions, the eruptions may have been caused by a large meteorite impact.

2 **FROM HERE...**
During the Cretaceous Period, intense volcanic activity on Earth caused frequent, copious eruptions of lava and ash that exterminated the dinosaurs. Over 386 square miles (1,000 sq km) of volcanic rock deposited on the Deccan Plateau in India lend credence to this scientific hypothesis of the Cretaceous extinction.

3 **...OR FROM THERE**
As the Solar System crosses the galactic plane of the Milky Way, every 67 million years it changes the paths of meteoroids and comets in the Oort cloud. These bodies could enter the inner Solar System as meteors and possibly strike the Earth as meteorites.

50 million
ATOMIC BOMBS like the one dropped on Hiroshima equal the force of the impact of one meteorite measuring 6 miles (10 km) in diameter.

Reptiles: Background

GOOD VISION
Iguanas have very good vision. They see colors, and they have transparent eyelids that close easily.

A SKIN WITH SCALES 32-33
THE FAMILY TREE 34-35
A LIVING FOSSIL 36-37
INTERNAL ORGANS 38-39
A MENU AT GROUND LEVEL 40-41
REPRODUCTION 42-43

Color plays a very important role in the life of iguanas and lizards. It helps to differentiate males and females, and when it is time to attract a mate, the members of the iguana family communicate by showing bright colors, tufts of feathers, and folds of skin. Another particularity that distinguishes iguanas is their covering of epidermal scales. In addition, like all reptiles, they are not capable of generating internal heat, so they depend on external factors to maintain their body temperature. For this reason, you will frequently see iguanas lying stretched out in the sun.

When it comes to their diet, most reptiles are carnivores, with the exception of some turtles, which are herbivores. Reptiles are also characterized by their total independence from aquatic environments.

A Skin with Scales

Reptiles are vertebrates, meaning that they are animals with a spinal column. Their skin is hard, dry, and flaky. Like birds, most reptiles are born from eggs deposited on land. The offspring hatch fully formed without passing through a larval stage. The first reptiles appeared during the height of the Carboniferous Period in the Paleozoic Era. During the Mesozoic Era, they evolved and flourished, which is why this period is also known as the age of reptiles. Only 5 of the 23 orders that existed then have living representatives today.

SOLOMON ISLAND SKINK
Corucia zebrata

EMBRIONARY MEMBRANES
They develop two: a protective amnion and a respiratory allantoid (or fetal vascular) membrane.

Squamata

This order constitutes the largest group of living reptiles and includes more than 6,000 species of lizards and snakes. The majority of animals in this order have bodies that are covered with corneous scales. The squamata include three forms of reptiles that are somewhat different from each other: the amphisbaenians, the lizards, and the snakes. It also contains certain extinct forms of reptiles, including pythonomorpha, which had snakelike bodies and lizard-like feet.

APPROXIMATELY **2,900** SPECIES OF SNAKES EXIST.

BOA CONSTRICTOR
Boa constrictor

They regulate their temperature by taking advantage of different sources of external heat, such as direct sunlight and stones, tree trunks, and patches of ground that have been heated by the sun.

ECTOTHERMIC
The body temperature of reptiles depends on the environment—they cannot regulate it internally. This is why higher temperatures increase their vitality.

SKIN
Dry, thick, and impermeable, it protects the body from dehydrating even in very hot, dry climates.

EYES
are almost always small. In diurnal animals, the pupil is rounded.

NICTITATING MEMBRANE
extends forward from the internal angle of the eye and covers it.

4,765 SPECIES OF LIZARDS EXIST.

ROSY BOA
Charina trivirgata

THE TONGUE
Large, protractile, and bifid, a reptile's tongue is very short and thick, and it contains the taste organs.

Habitat

Reptiles have a great capacity to adapt, since they can occupy an incredible variety of environments. They live on every continent except Antarctica, and most countries have at least one species of terrestrial reptile. They can be found in the driest and hottest deserts, as well as the steamiest, most humid rainforests. They are especially common in the tropical and subtropical regions of Africa, Asia, Australia, and the Americas, where high temperatures and a great diversity of prey allow them to thrive.

BLACK CAIMAN
Melanosuchus niger

Chelonians

The order of the testudines differentiated itself from the rest of the reptile world during the Triassic Period. Today it comprises marine turtles and terrestrial turtles. The species of this order are unique. They are covered with shells that consist of a dorsal carapace and a ventral plastron. These shells are so much a part of these animals that their thoracic vertebrae and ribs are included in them. Since these rigid shells do not allow turtles to expand their chests to breathe, these animals use their abdominal and pectoral muscles like diaphragms.

HERMANN'S TORTOISE
Testudo hermanni

Crocodiles

are distinguished by their usually large size. From neck to tail, their backs are covered in rows of bony plates, which can give the impression of thorns or teeth. Crocodiles appeared toward the end of the Triassic Period, and they are the closest living relatives to both dinosaurs and birds. Their hearts are divided into four chambers, their brains show a high degree of development, and the musculature of their abdomens is so developed that it resembles the gizzards of birds. The larger species are very dangerous.

OVIPAROUS
Most reptiles are oviparous (they lay eggs); however, many species of snakes and lizards are ovoviviparous (they give birth to live offspring).

THORAX AND ABDOMEN
are not separated by a diaphragm. Alligators breathe with the help of muscles on the walls of their body.

AMERICAN ALLIGATOR
Alligator mississippiensis

300 SPECIES OF TURTLES EXIST.

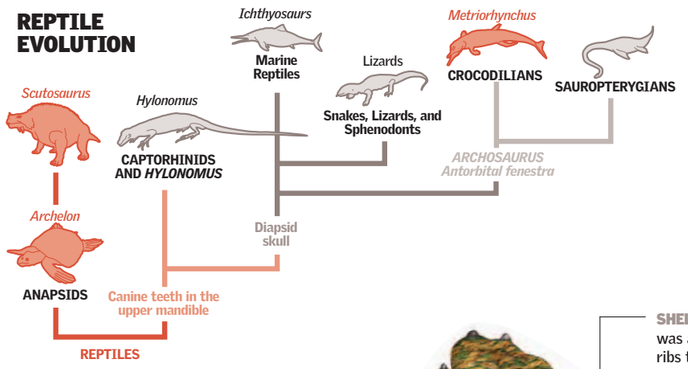
LUNGS
Since the ribs are fused with the shell, turtles cannot move their ribs to inhale. They use the muscles in the upper part of their legs to produce a pumping motion and inhale air.

SKELETON
is almost entirely ossified (not cartilaginous).

CENTRAL AMERICAN RIVER TURTLE
Dermatemys mawii

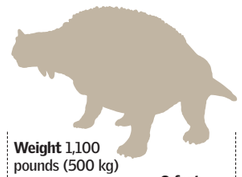
The Family Tree

The first reptiles descended from ancestral amphibians. They distinguished themselves from their ancestors through mutations that allowed them to free themselves from their dependence on water for reproduction. Among these adaptations, the amniotic egg stands out, but equally important were the development of sex organs that favored internal copulation, an impermeable skin, and the formation of a low volume of urine that eliminates uric acid instead of urea. These adaptations to its environment were necessary to the reptilian dominance of the greater part of the Mesozoic Era.



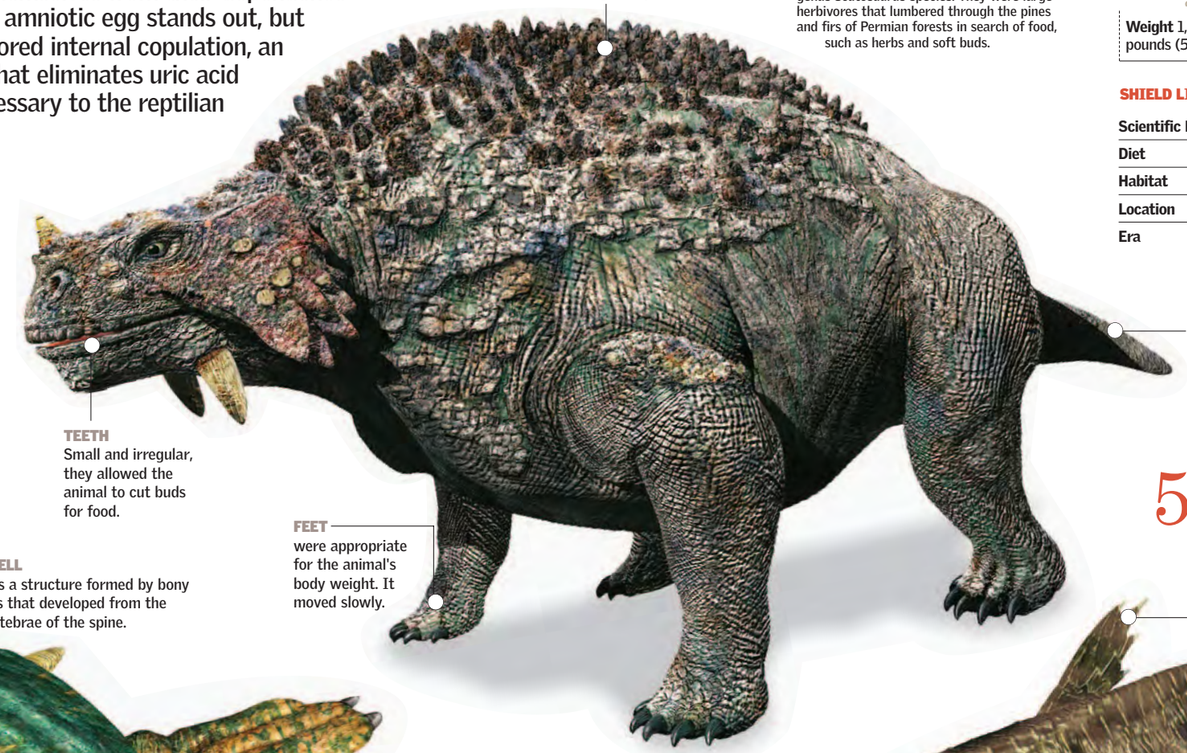
Tough Skin

Scutosaurs were quadrupeds with massive legs, similar to strong columns with wide bases, which sustained the weight of their bodies. These reptiles belonged to the extinct genus *Scutosaurus* species. They were large herbivores that lumbered through the pines and firs of Permian forests in search of food, such as herbs and soft buds.



SHIELD LIZARD

Scientific Name	*Scutosaurus* sp.
Diet	Herbivore
Habitat	Land
Location	Europe (Russia)
Era	End of Permian



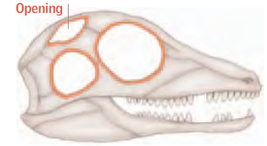
5 ORDERS OF REPTILES EXIST TODAY.

Skull Types

The fossils of the most primitive reptiles correspond with the Lower Carboniferous Period. These reptiles were terrestrial animals, somewhat similar to the Mesozoic reptiles. The diapsid lineage originated with them.

ANAPSID

A group of reptiles without openings in the skull near the temples. This is the condition seen in fish, amphibians, and earlier reptiles. Today's turtles belong to this lineage.

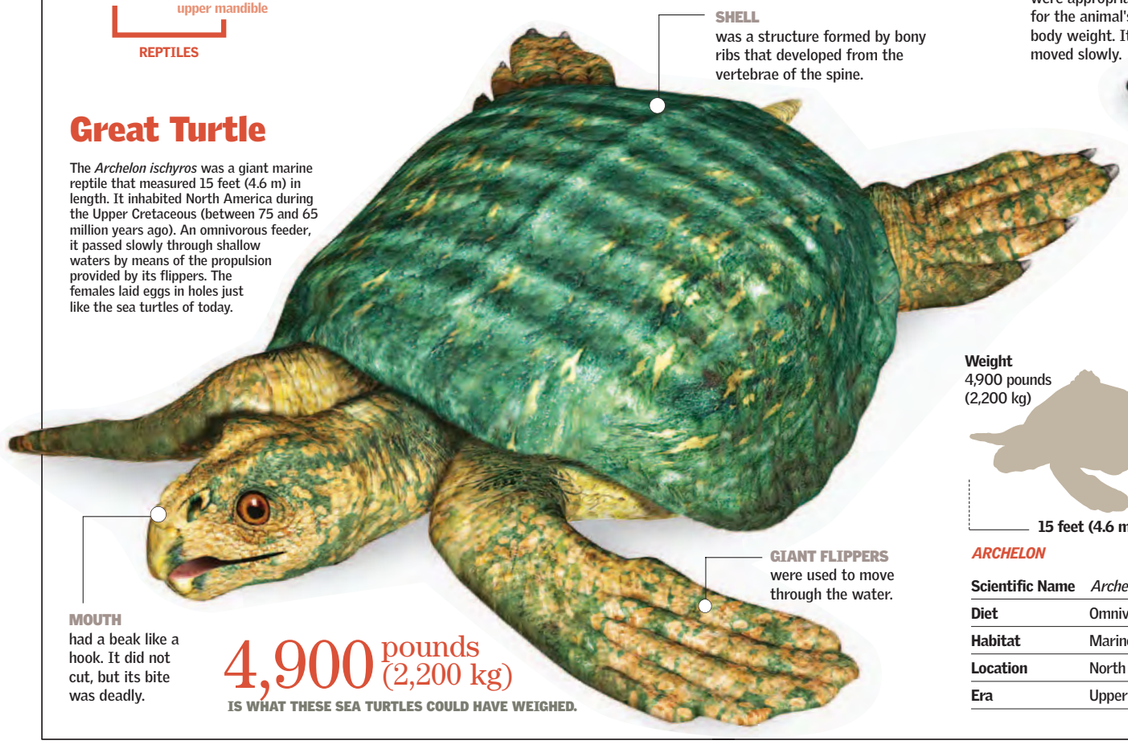


DIAPSID

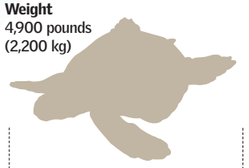
During the Permian Period, another group of reptiles emerged that had temporal openings in the skull behind each eye socket.

Great Turtle

The *Archelon ischyros* was a giant marine reptile that measured 15 feet (4.6 m) in length. It inhabited North America during the Upper Cretaceous (between 75 and 65 million years ago). An omnivorous feeder, it passed slowly through shallow waters by means of the propulsion provided by its flippers. The females laid eggs in holes just like the sea turtles of today.

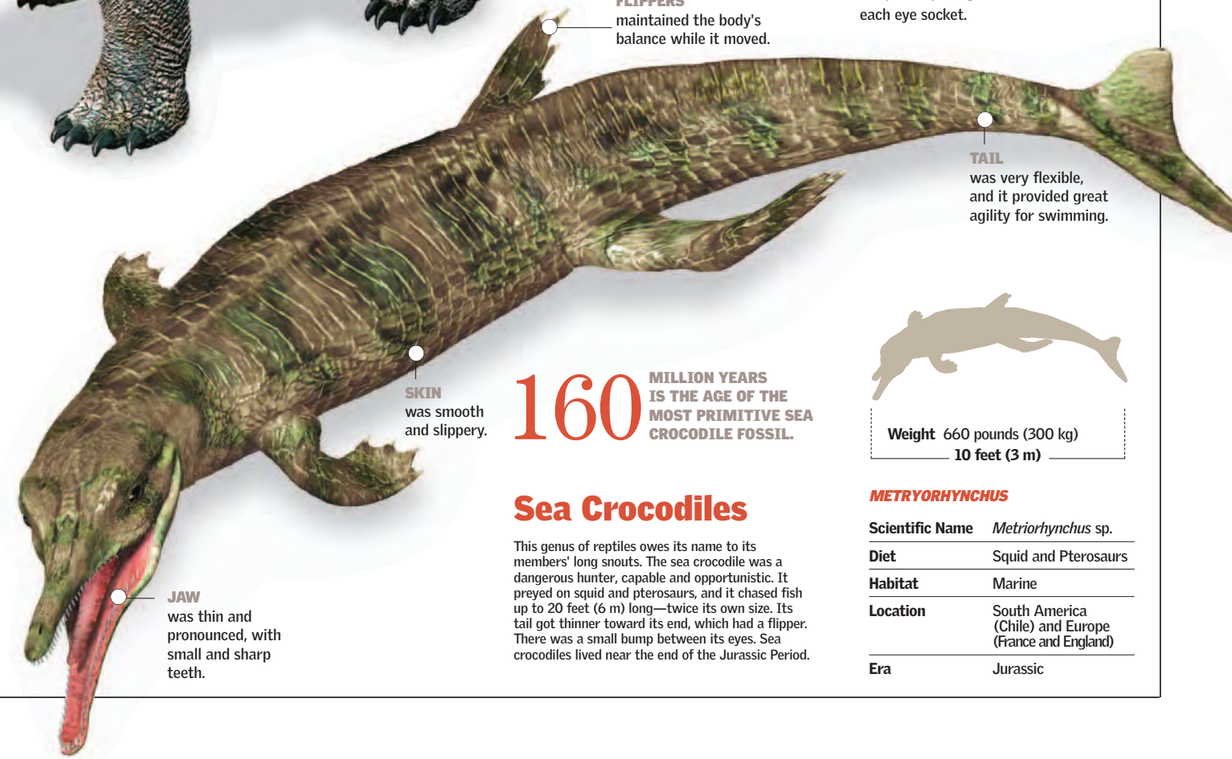


4,900 pounds (2,200 kg) IS WHAT THESE SEA TURTLES COULD HAVE WEIGHED.



ARCHELON

Scientific Name	*Archelon ischyros*
Diet	Omnivorous
Habitat	Marine
Location	North America
Era	Upper Cretaceous



160 MILLION YEARS IS THE AGE OF THE MOST PRIMITIVE SEA CROCODILE FOSSIL.

Sea Crocodiles

This genus of reptiles owes its name to its members' long snouts. The sea crocodile was a dangerous hunter, capable and opportunistic. It preyed on squid and pterosaurs, and it chased fish up to 20 feet (6 m) long—twice its own size. Its tail got thinner toward its end, which had a flipper. There was a small bump between its eyes. Sea crocodiles lived near the end of the Jurassic Period.

METRYORHYNCHUS

Scientific Name	*Metriorhynchus* sp.
Diet	Squid and Pterosaurs
Habitat	Marine
Location	South America (Chile) and Europe (France and England)
Era	Jurassic

A Living Fossil

Despite looking like lizards and sharing some common traits with crocodiles, tuataras are a unique type of reptile. The tuatara is the last living sphenodont, and, because it has changed very little from its original form, it is called a living fossil. Two known species of tuatara have been identified, both of which inhabit the islands that lie off the coast of New Zealand. They live in burrows, and their great tolerance for cold allows them to survive at very low temperatures. Tuataras grow slowly and can live up to 80 years.

TUATARA
Sphenodon punctatus

Habitat	**Stephens Island**
Reproduction	**Oviparous**
Lifestyle	**Burrower**

The males are much larger than the females.

Weight
25 ounces (700 g)

Average Length: 16 to 24 inches
(40 to 60 cm)

"Spiny back"

IS THE MEANING OF "TUATARA" IN THE MAORI LANGUAGE

TAIL
Tuataras can shed their tails to avoid being captured. The lost portion grows back, but it differs both in color and in design from the original tail.

PINEAL EYE
can be distinguished in younger specimens. In adults, it is covered by the scales that grow over it.

SPINES
These smooth and conspicuous spines are more prominent in males.

FEET
have four toes apiece.

HEAD
is large compared to the body, and it lacks auditory structures.

SKULL
has two openings (temporal fenestra) on either side of the skull.

Openings behind each eye (temporal fenestra)

TEETH
are not separated structures but rather a sharpened extension of the edges of both jaws.

NUTRITION
Tuataras are carnivores. Their diet consists of insects, earthworms, snails, and crickets. Occasionally they eat shearwater eggs and nestlings.

EYE
is large. The pupil is a vertical slit, and the iris is a dark brown color.

COLORATION
Tuataras' tones vary from grayish to olive to brick red. Tuataras undergo significant variations in color throughout their lives.

SCALES
on its back are small and granular, while the ones on its stomach are arranged in transverse rows.

150 million years

THE LENGTH OF TIME TUATARAS HAVE EXISTED WITHOUT UNDERGOING EVOLUTIONARY CHANGES.

REPRODUCTION
Females are ready to mate once every four years. The male—the only modern living reptile without a penis—uses its cloaca to transfer its sperm directly into the female cloaca.

THE EGGS
take a year to form inside the body of the mother and another year to incubate.

68° F (20°C)
There is an 80 percent chance that the eggs will hatch female.

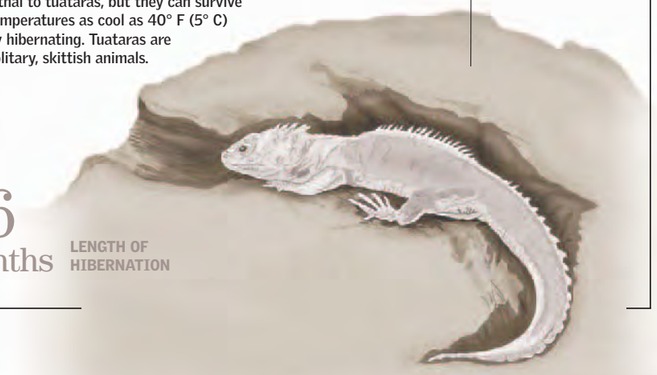
70° F (21°C)
There is a 50 percent chance that they will hatch female.

72° F (22°C)
There is an 80 percent chance that they will hatch male.

Behavior

Tuataras are nocturnal. During the day, they rest on rocks basking in the sun, and at night, they go out hunting near their burrows. Tuataras, unlike other reptiles, thrive in cold weather. Temperatures above 77° F (25° C) are lethal to tuataras, but they can survive temperatures as cool as 40° F (5° C) by hibernating. Tuataras are solitary, skittish animals.

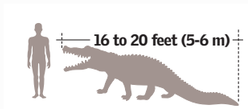
BURROW
A tuatara can dig its own burrow or inhabit that of another.



6 months LENGTH OF HIBERNATION

Internal Organs

The anatomy of reptiles enables them to live on land. Thanks to their dry, scaly skin and their excretion of uric acid instead of urea, they minimize water loss. The heart distributes blood in a double circuit. Crocodiles were the first vertebrates to have a four-chambered heart; the separation of the ventricles is incomplete in all other reptiles. The lungs, developed beyond those of amphibians, contribute to cardiac efficiency by allowing for greater exchange of gases.

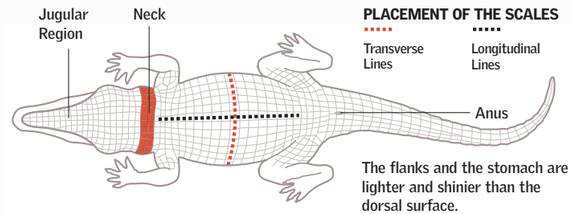


Weight: more than 1 ton

NILE CROCODILE
Crocodylus niloticus

Diet	Carnivorous
Longevity	45 years in the wild and 80 years in captivity

SKIN
Reptiles have chromatophores that modify their color to a small degree. Two unique traits of crocodiles are that the skin on the head has glands that regulate the body's ionic balance, and the cloaca has glands that secrete substances crucial for mating and defense.

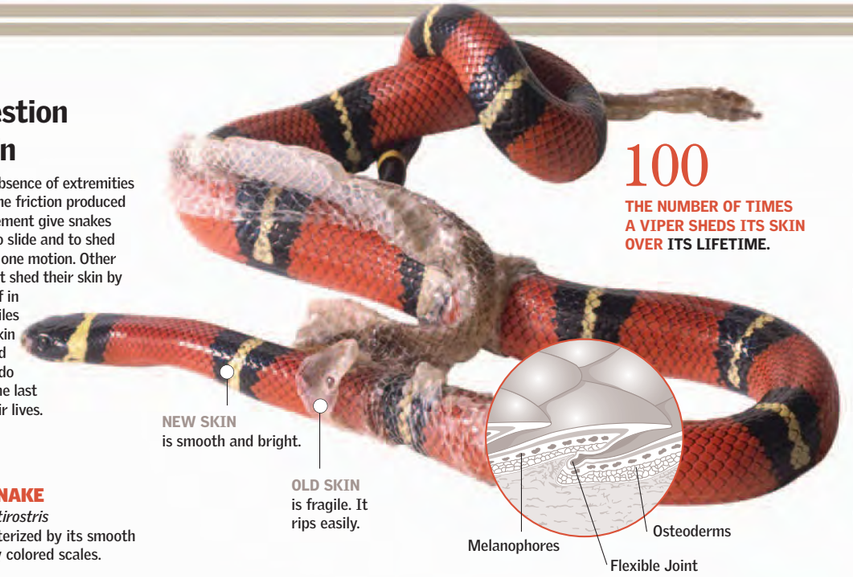


The flanks and the stomach are lighter and shinier than the dorsal surface.

A Question of Skin

The absence of extremities and the friction produced during movement give snakes the ability to slide and to shed their skin in one motion. Other reptiles must shed their skin by tearing it off in pieces. Reptiles shed their skin regularly and continue to do so even in the last years of their lives.

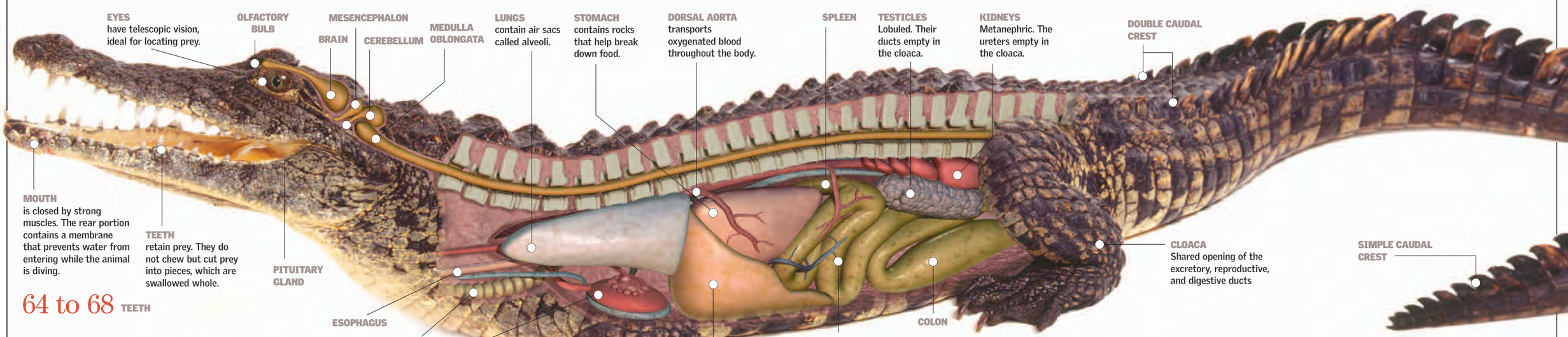
CORAL SNAKE
Micrurus altirostris
It is characterized by its smooth and brightly colored scales.



100
THE NUMBER OF TIMES A VIPER SHEDS ITS SKIN OVER ITS LIFETIME.

GROWTH OF THE SCALES

1. The dermal layer is found below the epidermis.
2. Differentiation takes place during dermal cell growth.
3. The epidermis secretes large amounts of keratin.
4. The new scales overlap each other and cover the skin.



64 to 68 TEETH

Circulatory System

Nile crocodiles have double circulation. A minor circuit brings deoxygenated blood to the lungs and transports oxygenated blood from them, and a major circuit transports the oxygenated blood to the rest of the body and returns deoxygenated blood to the heart. Reptile hearts have two auricles (atria) and a single ventricle, which is partially divided by an incomplete ventricle partition.

THE HEART
The flow patterns inside the heart prevent the mixing of pulmonary and systemic blood.

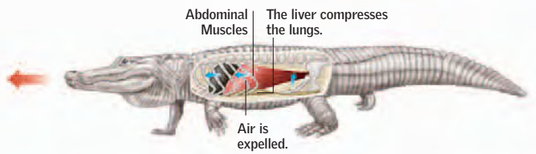
BLOOD CIRCULATION
An ample and efficient network of blood vessels extends throughout the bodies of reptiles.

Respiratory System

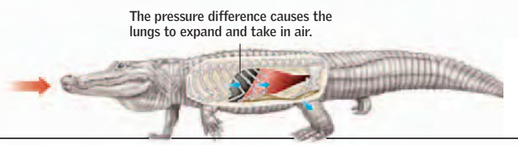
is completely pulmonary. Most reptiles possess a pair of functional lungs, with the exception of snakes, which have only one functional lung. Body-wall muscles generate the pressure differences necessary to circulate air through the airways from the nasal cavities to the pulmonary alveoli.

BREATHING

1. **EXHALING**
Internal organs are compressed. This, in turn, compresses the lungs and causes them to expel air.



2. **INHALING**
The pelvic bones rotate downward, the abdomen stretches, and the muscles cause the lungs to expand.



A Menu at Ground Level

Reptiles are basically carnivorous, even though some follow other food regimens. Lizards usually feed on insects. Snakes usually feed on small vertebrates like birds, rodents, fish, amphibians, or even other reptiles. For many, the eggs of birds and other reptiles make a very succulent meal. The painted turtle is omnivorous: it eats meat and plants. Reptiles and other species are part of a larger food chain—animals eat other animals, preserving the equilibrium of the environment.

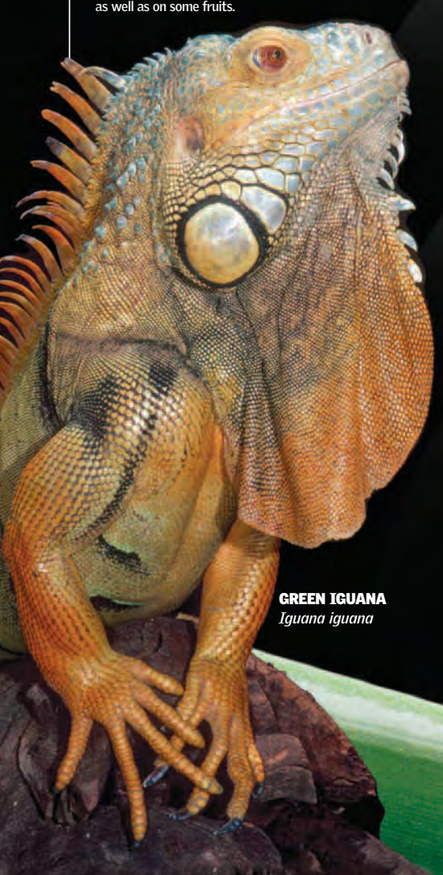
SNAKES
can expand both their mouths and parts of their digestive tracts to swallow their prey whole. Their teeth and fangs are not for chewing but for hunting, poisoning, and retaining their prey.

X-RAY IMAGE
This snake swallowed a frog whole.

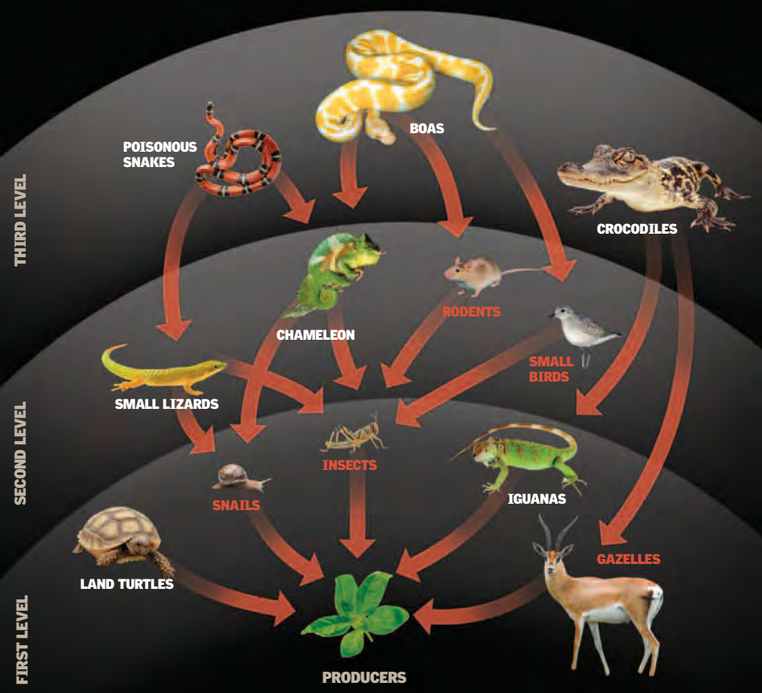
Herbivores

This diet is generally typical of other groups of animals; however, there are reptiles that feed only on green leaves and plants. The marine iguana eats only the algae that it finds under rocks on the sea floor.

GREEN IGUANA
Also called the common iguana, it is one of the few herbivorous reptiles. It feeds on green leaves as well as on some fruits.



GREEN IGUANA
Iguana iguana



The Food Chain

Because they use photosynthesis, which permits inorganic carbon to be transformed into organic material, plants are the only true "producers" in the food chain. Herbivores feed on them and are thus first-level consumers. The animals that feed on the herbivores are second-level consumers, and the animals that eat other carnivores—a category that includes some reptiles—form the third level of consumers in the food chain.

Metabolism

In the case of snakes that swallow their prey whole, digestion takes weeks and sometimes even months. Their gastric juices digest even the bones of their prey.

Carnivores

The tools in a predator reptile's kit include an opportunistic instinct, well-developed reflexes, mucous glands in the mouth that lubricate its prey, a potent immune system, and a tongue with olfactory nerve endings.

CROCODILES
feast on invertebrates and other vertebrates. Crocodile young mainly consume terrestrial and aquatic invertebrates, whereas the adults feed primarily on fish.

WOOD TURTLE
Clemmys insculpta

Omnivores

Turtles may be slow, but many include mollusks, worms, and slow-moving insect larvae among the items on their otherwise vegetarian menu. The loggerhead sea turtle, which measures over 6.5 feet (2 m) long, eats sponges, mollusks, crustaceans, fish, and algae.

EYELASH VIPER
Bothriechis schlegeli

Reproduction

Most reptiles are oviparous. Some species lay large numbers of eggs and then allow them to develop on their own, generally in well-protected nests or hidden under dirt or sand. Marine turtles, especially green turtles, travel to the coast to lay their eggs in the sand, where they are left at the mercy of all who pass by. The females of other species, however, fiercely protect their offspring, staying near their nests for long periods of time to scare away potential predators.

GREEN ANACONDA
Eunectes murinus
An anaconda can have more than 50 offspring, which measure nearly 3 feet (1 m) long at birth.

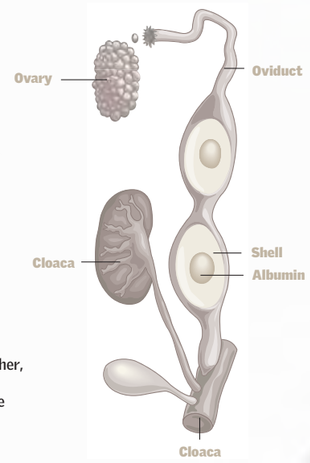
Eggshells

Reptile offspring develop within a liquid-filled sac called the amnion, which lies inside the egg. Most reptile eggs have soft, flexible shells, but some have much harder shells. Through the shell, the hatchling absorbs the oxygen and moisture it needs for growth, while its yolk provides it with food.

Oviparous

Reproduction that involves laying eggs in which the offspring complete their development before hatching. Some species lay large numbers of eggs and then allow them to develop on their own, generally in well-protected nests or hidden in dirt or sand. In other species, such as crocodiles, the females fiercely protect their offspring.

THE FEMALE REPRODUCTIVE SYSTEM
has two ovaries that contain the ovules, leading into two oviducts that reach the cloaca. Fertilization occurs in the forward part of the oviduct.



1 Growth

The egg is buried by the mother, and the embryo begins to develop. The egg provides the necessary oxygen and food.

2 Fracture

The pressure exerted on the shell from the movements of the animal within such a cramped space causes the shell to break from the inside.

EGG TOOTH
A corneous, or horny, spine on the beak for breaking the shell during hatching

3 Hatching

The turtle is ready to come out and starts to break the egg with its body. Hatching occurs.

Ovoviviparous

The eggs remain in the mother's body, and hatching occurs there. The hatched young are diminutive versions of adult animals. Already independent, they do not receive any care from their parents.

145 to 160 days
IS THE INCUBATION PERIOD OF THE LEOPARD TORTOISE.

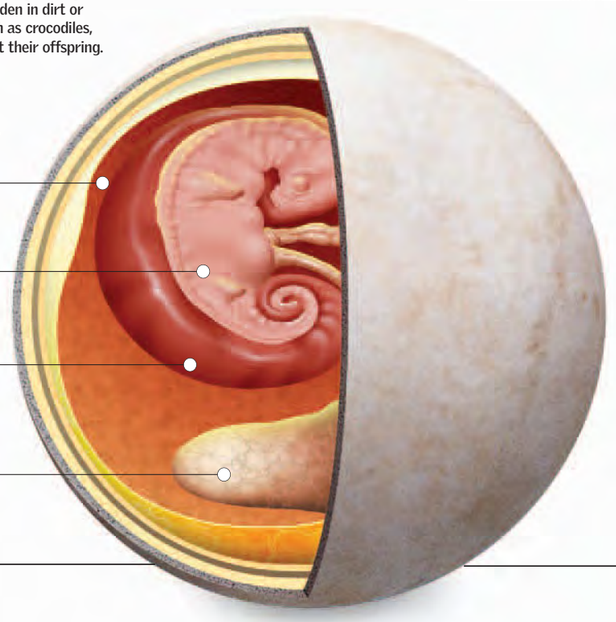
4 Exit

It can take the baby animal an entire day to exit, and it will have a small sac hanging from its navel. This is the sac of yolk that provided it with food while it was incubating.

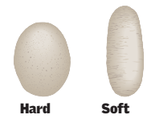
LEOPARD TORTOISE
Geochelone pardalis

Habitat	**Africa**
Diet	**Herbivorous**
Size	**23-26 inches** (60-65 cm)
Weight	**77 pounds** (35 kg)

LEOPARD TORTOISE



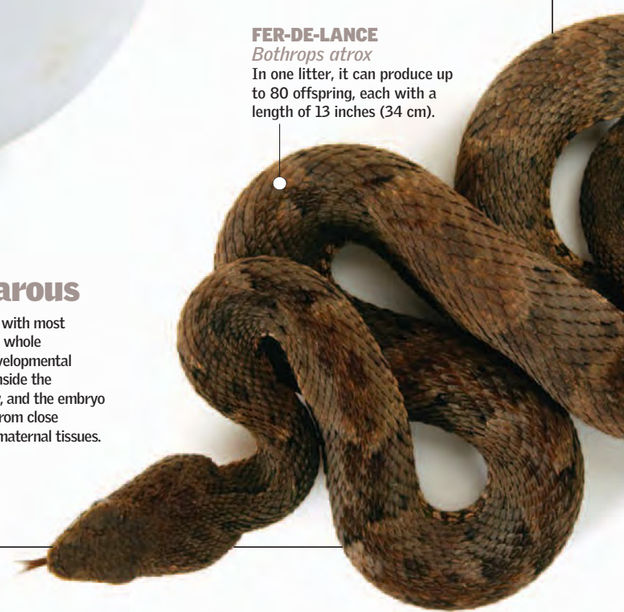
CONSISTENCY OF THE EGGS
The eggshell can be soft or hard. Soft eggshells are usually found in lizards and snakes, whereas hard eggshells are common in turtles and crocodiles.



Viviparous

As is the case with most mammals, the whole embryonic developmental cycle occurs inside the mother's body, and the embryo obtains food from close contact with maternal tissues.

FER-DE-LANCE
Bothrops atrox
In one litter, it can produce up to 80 offspring, each with a length of 13 inches (34 cm).



Lizards and Crocodiles

THORNY DEVIL
This Australian lizard gets its name from the sharp spines that cover its body. It can consume up to 2,500 insects in one meal.

LIZARDS 46-47
KOMODO DRAGON 48-49
MARINE IGUANA 50-51
GECKOS 52-53
CHANGING COLORS 54-55
VENERATED AND FEARED 56-57
THE LARGEST ON THE NILE 58-59
THE AMERICAN EXAMPLE 60-61

Because of their long, powerful bodies and sharp teeth, crocodiles are among the most dangerous predators. When they are small, they eat small fish, frogs, and insects. When fully grown, however, they can devour large animals and even humans. We invite you to learn more about the life and habits of these animals. Did you know that lizards are the most numerous reptiles in the world today? This group includes a wide variety of species of all shapes and sizes. They all belong to the taxonomic group Sauria, and most are carnivores. The Komodo dragon of Indonesia eats wild hogs, deer, and monkeys and can weigh nearly 300 pounds (135 kg). ●

Lizards

Lizards are the largest group of reptiles. They live in most environments except for extremely cold regions, since they cannot regulate their own body temperatures. There are land-dwelling, underground, tree-dwelling, and even semi-aquatic lizards. They can walk, climb, dig, run, and even glide. Lizards often have differentiated heads, movable eyelids, a rigid lower jaw, four five-toed feet, a long body covered with scales, and a long tail. Some can even shed their tails when threatened.

DAY GECKOS
Phelsuma sp.

STICKY TOES

Chameleons

live in Africa, especially in southeastern regions and on Madagascar. They live in forests, where they use their prehensile tails and toes to climb trees. Their well-known ability to change color is important when they face danger or when they begin to court.

Camouflage

is an adaptive advantage. By blending in with the vegetation surrounding them, lizards can escape the notice of both their predators and their prey.

LIFESAVING RECOURSE
Between each vertebra, there are rupture planes enabling the tail to separate from the body.

AUTOTOMIC TAIL
Certain lizards can shed their tails many times during their lives. In dangerous situations, they may even shed it voluntarily in order to flee their confused predators. Later the tail grows back.

TELESCOPIC EYES

MELLER'S CHAMELEON
Chamaeleo melleri

SKIN
has cells with many pigments.

TAIL
curls up when necessary.

PREHENSILE TOES
can surround a branch and hold on tight.

Geckos and Skinks

are lizard-like animals of the family Gekkonidae that live in warm regions. Their limbs are very small. (In fact, some species have none at all!) Their bodies are covered with smooth, shiny scales.

4,765
LIZARD SPECIES EXIST IN THE WORLD.

Heloderma

comprise only two species, which live in the United States and Mexico. They feed on invertebrates and small vertebrates. Their bodies are massive, and their skin is covered with small knobs. They are the only poisonous lizards, and their bite can be dangerous to humans.

COLORS
warn of poison.

GILA MONSTER
Heloderma suspectum

FAT TAIL
stores fat reserves for later consumption.

NOSTRIL

EYE WITH EYELID

EAR

MOUTH

CREST
runs from head to tail.

SKIN
has scales covered with a tough, corneous (or hornlike) layer.

CREST

SUBTYMPANIC SHIELD

DEWLAP
is fleshy and large in males.

COMMON IGUANA
Iguana sp.

FEET WITH CLAWS
enable it to walk, climb, and dig burrows.

CLAW

Body Heat

Lizards survive in environments where they can maintain their body temperature, such as forests or deserts.

SUNBATHING
6:00 AM
The lizard places its body in the sun's rays to take advantage of their heat.

IN ACTION
10:00 AM
It begins its daily activities and movements.

HIDDEN
12:00 PM
When the sun is at its highest, they hide from the excessive heat.

CATCHING A FEW MORE RAYS
6:00 PM
They return to the sunlight but elevate their bodies to take advantage of the heat radiating from the rocks.

Iguanas

Iguanas belong to the largest New World group of reptiles and have the most complex design. They inhabit tropical regions of the Americas, including the forests of Mexico. They can change color during mating season. The species of this group are vegetarians.

Komodo Dragon

This animal is the largest lizard in the world. It is related to monitor lizards and can grow up to 9.8 feet (3 m) long and weigh up to approximately 330 pounds (150 kg). These endangered lizards live only on a group of islands in Indonesia. They are carnivorous and are known for their ferocity in attacking their prey. Their saliva is full of bacteria that can kill their prey with only one bite. They can detect other Komodo dragons from several miles away.

KOMODO DRAGON
Varanus komodoensis

Habitat (approx.)	**900 square miles** (2,300 sq km)
Number of Dragons	**Less than 5,000**

TOUGH SKIN
is covered with black, brown, or dark gray scales.

CLAWS
Its five claws are very sharp. It uses them to hold onto its dying prey.

SIZE AND WEIGHT
Males can grow more than 10 feet long. Females are somewhat smaller.

STOMACH
Like most reptiles, Komodo dragons have a stomach that can expand enormously. This enables them to gulp down up to 70 percent of their own weight in a single meal.

5,000

LIZARDS
of the family Varanidae live in the wild on six small Indonesian islands, including Komodo Island.

How It Attacks Its Prey

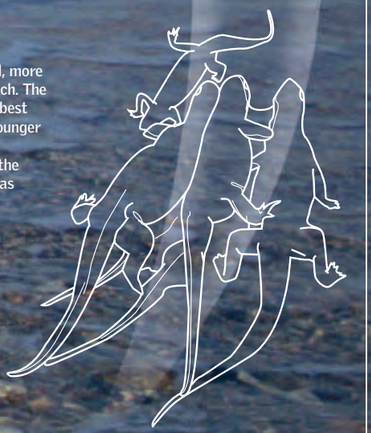
1 SEARCH
The dragon searches for food with its forked tongue. When chasing its prey, it can reach speeds of up to 11 miles (18 km) per hour.

SMELL
They have an acute sense of smell that can detect the odor of decomposing flesh at a distance of up to 3 miles (5 km).

2 BITE
Following the scent, the dragon captures its prey, which dies after being bitten. Its favorite prey is deer and wild boars.

3 FEEDING
The dragon feeds rapidly, using the flexible joints of its jaws and skull. It digests not only chunks of meat but also the skin and bones of its prey.

4 STRUGGLE
Smelling a meal, more dragons approach. The largest get the best portions. The younger ones keep their distance, since the adults may act as cannibals.



SALIVA
contains bacteria that are harmful to its prey. Antibacterial substances in the Komodo dragon's blood protect it from their harmful effects.

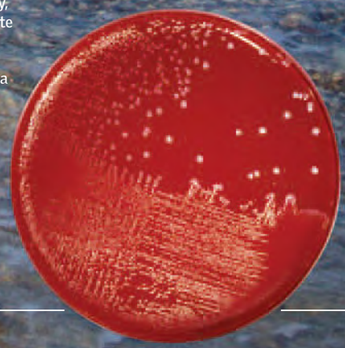
TONGUE
is forked and is used for tasting, smelling, and feeling. It can perceive various airborne particles, helping it detect prey.

A Long Hunt

Komodo dragons have an acute sense of smell that can detect the presence of other animals up to 2 miles (3 km) away. They track their prey using their forked tongues to detect scents from molecules in the air. Jacobson's organ, located inside the mouth, helps the lizard to locate its prey more rapidly and consume less energy while tracking it.

Deadly Saliva

The saliva of Komodo dragons is full of bacteria that can quickly kill its prey by causing septicemia. To kill its prey, the Komodo dragon only needs to bite it once. An analysis of its saliva revealed 60 types of bacteria, 54 of which cause infection. These bacteria are known to cause putrefaction of dead animals, including the bacteria *Pasteurella multocida* (one of the deadliest), *Streptococcus*, *Staphylococcus*, *Pseudomonas*, and *Klebsiella*. When combined, they are a deadly weapon.



PASTEURELLA MULTOCIDA
Bacteria that affects the gastrointestinal and respiratory tracts of mammals and birds

Marine Iguana

The Galapagos Islands, besides serving as a home for many species of the Central Pacific and South America, also have an amazing number of indigenous species. One of these is the marine iguana, the only species of iguana in the world that spends most of its time in the water. This reptile lives on the rocky coasts and feeds on seaweed and algae. It can stay underwater for 45 minutes and dive approximately 50 feet (15 m) deep. This unique, slow-swimming creature gathers seaweed to eat at low tide or dives for food.

Life in Colonies

The marine iguana is native to the Galapagos Islands and is the only lizard that finds its food in the sea. It lives in colonies, which is a curiosity given the solitary behavior of other iguanas. When they are not feeding, marine iguanas stretch out on rocks to warm in the sun. Thousands may be seen on one area of the beach. However, their peaceful coexistence disappears during mating season when males fight aggressively over females. The females reestablish harmony at nesting time. Since there is little space for the nests, thousands of females lay their eggs together. Each one can lay from one to six eggs, which are placed in a sandy burrow.

SCALY BACK

LEGS
are kept to the side of the body while swimming.

TAIL
can be used as a whip in self-defense.

MARINE IGUANA
Amblyrhynchus cristatus

Habit	Semi-aquatic
Length	20-40 inches (50-100 cm)
Range	Galapagos Islands

Weight
24 pounds (11 kg)

40 inches (1 m)

The Galapagos Islands

consist of 13 major islands, six small islands, and many islets, all of which are volcanic in origin. Located along the Equator, some 620 miles (1,000 km) west of the South American landmass, they are part of the territory of Ecuador. Their climate varies widely because of the different ocean currents that converge around the archipelago. Because of their isolation, they are home to many indigenous species, most of which are birds and reptiles.

45 MINUTES UNDERWATER WITHOUT AIR
is the maximum amount of time that a marine iguana can stay submerged while looking for food.

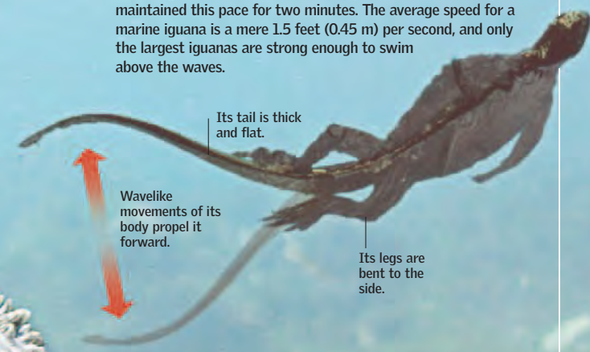
SPINES
The crest is usually larger in males. When fighting for a female, they strike their crests against their opponents.

SEAWEED
The different kinds of seaweed that grow on the islands may cause these reptiles to vary in color from one island to another.

CLAWS
are longer and sharper than those of land-dwelling iguanas, allowing the animals to cling to rocks to avoid being swept away by waves.

Swimming

English naturalist Charles Darwin described the marine iguana's style of swimming as "agile and rapid," but later studies and observations revealed the opposite. This animal, found only on the Galapagos Islands, swims very slowly and with very little energy. The fastest swimming speed recorded for a marine iguana was 2.8 feet (0.85 m) per second, and it only maintained this pace for two minutes. The average speed for a marine iguana is a mere 1.5 feet (0.45 m) per second, and only the largest iguanas are strong enough to swim above the waves.



Feeding Habits

The largest marine iguanas eat seaweed in the water, but the smaller and younger ones do not. Although adult iguanas can dive to a depth of about 50 feet (15 m), in normal conditions they feed at low tide in dives that last less than 10 minutes. Young iguanas, however, stay out of the water because their body temperature could fall rapidly. They can only feed on seaweed that grows on exposed rocks and is deposited at high tide.

SALT
Between its eyes and its nostrils, the marine iguana has glands to expel salt from its body. By exhaling strongly, it emits a jet of air that scatters the salt, which falls on its head and forms a white crest.

Geckos

Geckos are a group of small, slender lizard species that live mostly in tropical and subtropical regions and on many islands in the oceans. Some species live in deserts, and many have burrows or make their homes in rock crevices. They are nocturnal and can flee from their predators by voluntarily shedding their tails. Geckos are the only lizards whose males produce sounds to attract females and to defend their territory. These agile climbers can walk on smooth vertical surfaces or even upside down by using tiny hairs on their feet that let them stick to anything they touch.

Leaf-Tailed Gecko

When hanging by its tail, it looks exactly like a leaf, which gave rise to its common name. Male geckos can produce sounds similar to vocalized calls. In this species, they are especially loud and high-pitched.

LEAF-TAILED GECKO

Scientific name	*Uroplatus henkeli*
Family	Gekkonidae
Habitat	Trees
Range	Madagascar, Africa
Diet	Carnivorous (insects)

1,050
SPECIES ARE IN THE GECKO FAMILY

Its tail is autotomic, meaning that the gecko can shed it, allowing the reptile to double its speed.

Its muscular legs are those of a great climber.

A gecko's skin is covered with tiny scales.

The texture of its skin helps it to blend into its environment.

Scaly Eyes

Unlike most lizards, geckos do not have movable eyelids. Their eyes are covered with a transparent membrane that they shed periodically, along with the rest of their skin.

Using its long, sticky tongue, the gecko cleans the membrane over its eyes and keeps it free of dust.

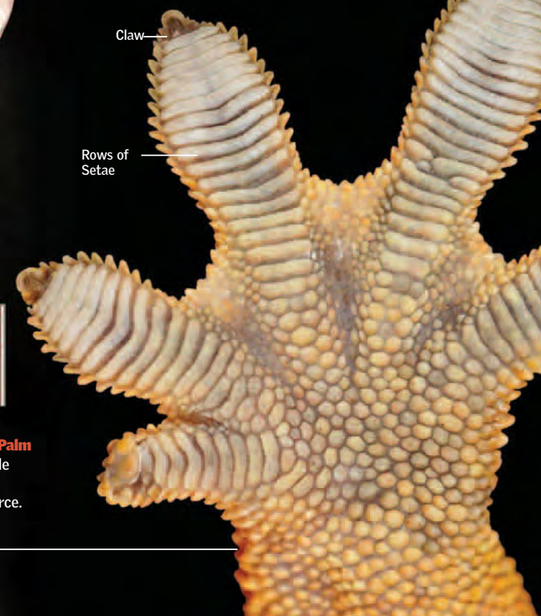
Geckos cannot blink. They have only a fixed lens, with an iris that enlarges in darkness.

Toes with Suckers

A gecko's feet end in toes surrounded by smooth membranes. They have 20 to 23 adhesive pads on the underside of the fourth toe. Geckos can climb directly upward and cling to smooth surfaces, because each toe has a disc with tightly packed concave areas that act as suckers.

SETAE
Geckos have tiny filaments on the ends of their toes called setae.

SPATULAE
Each seta ends in up to 1,000 microscopic hairs called spatulae.



Flight of the Gecko

The Kuhl's flying gecko lives in trees in Southeast Asia. Unlike flying lizards, it glides with its webbed feet. When it is not "flying," it spends most of its time hanging head down in the trees, ready for a rapid takeoff.

A Spreading Its Limbs
The membranes between its toes are used as wings for gliding.

B Arching Its Back
The membranes along its sides and flat tail help it to regulate its fall.

A Rare Phenomenon

Scientists have explained the gecko's capacity to cling (which even enables them to climb glass and never get it dirty) through electrostatic principles and even microphysics.

2 million
THE NUMBER OF HAIRS (SETAE) ON A GECKO'S FEET

Toes Backward
When walking, it moves them this way up to 15 times per second.

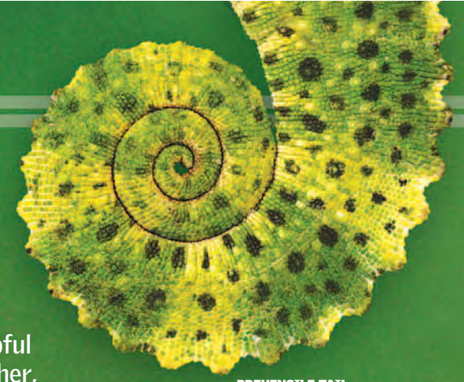
Touch Down and Support
The spatulae are very close to each other and to the surface.

Tiny Pieces
generate the same force that draws molecules together.

Raising the Palm
at a 30° angle breaks this attractive force.

Changing Colors

Chameleons are well known for their ability to change color. Another interesting fact is that their tongue can stretch great distances in seconds. They live mostly in Africa. Their prehensile tails and toes make them excellent climbers. Another helpful characteristic is that their eyes can move independently of one another, providing them a 360° field of vision. Their flat bodies help them to balance and to hide among the leaves.



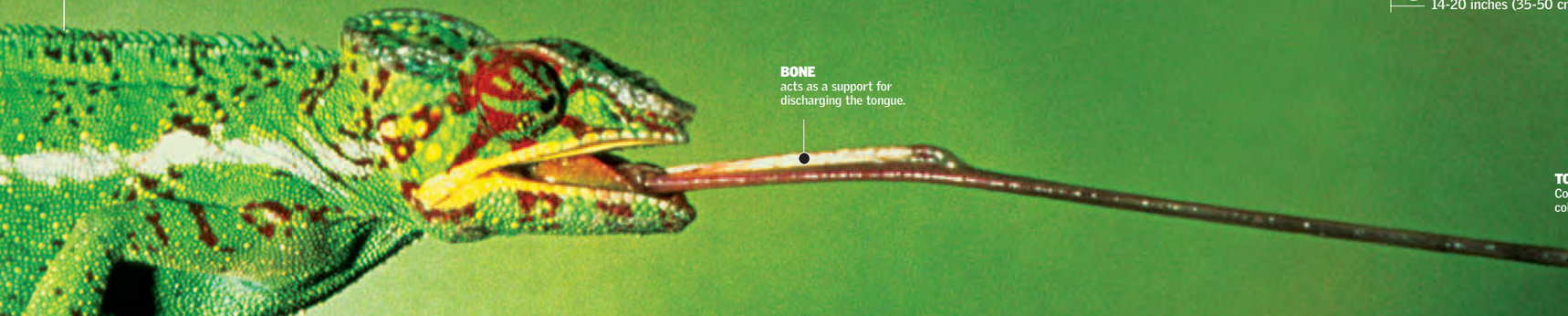
PREHENSILE TAIL
They use their long curved tails to hold on to branches without using their feet.

PANTHER CHAMELEON
Furcifer pardalis

Range	Madagascar
Habitat	Coastal Regions
Lifestyle	Diurnal

Feeding Habits

These diurnal hunters wait for victims to pass by. Their diet includes arthropods and small invertebrates. Among insects, they prefer crickets, grubs, cockroaches, and moths. Other species on the menu also include songbirds and mice.



BONE
acts as a support for discharging the tongue.

TONGUE
Covered with collagen tissue.

TIP
The tip of the tongue spreads out and captures the prey with its sticky surface.

Protractible Tongue

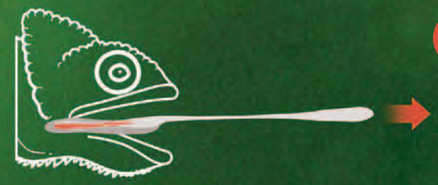
Long and lightweight, the chameleon's tongue is sticky and can be extended. Chameleons throw their tongues outward like projectiles to hunt their prey.

1 Contraction

Several sheets of collagen between the tongue and the accelerating muscle are compressed in the form of a spiral, which stores the energy necessary to propel the tongue outward.

2 Unfolding

The accelerating muscle compresses the energy-storing collagen tissues, launching the tongue toward its target.



3 Retraction

When the elastic tissues contract again, they roll up the tongue and return it to its initial position with the prey sticking to it.

Up to 600%

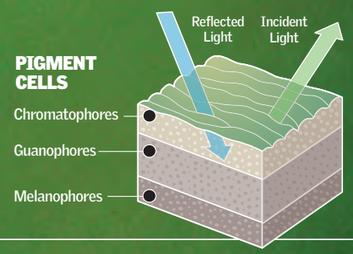
of the tongue's length is curled up in reserve.

FEET
The toes are divided into two parts, with two toes on the outside and three on the inside.

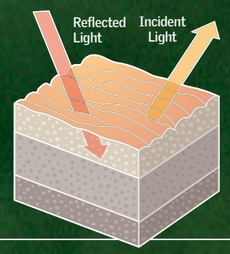
How It Changes Color

The color-changing ability of chameleons, well known in popular sayings and songs, is not an adaptation to the environment as is widely believed. Rather it is related to changes in light and temperature, courtship behaviors, or the presence of a predator. Color changes are caused by the action of hormones on pigment cells in the skin. These specialized cells, located in each layer of the dermis, react and change color, camouflaging the chameleon from its predators.

A When the upper layer (chromatophores) detects a yellow color, the blue light of the guanophores (white chromatophores) becomes greenish.



B The melanophores contain a dark pigment called melanin, which regulates the brightness and the amount of light reflected, varying its color.



Venerated and Feared

Crocodiles—along with their relatives, the alligators, caimans, and gavials—are very ancient animals. They belong to the same group that included the dinosaurs and have changed very little in the last 65 million years. They can go for long periods without moving; during these times, they sun themselves or rest in the water. However, they can also swim, jump, and even run at high speed to attack with force and precision. In spite of their ferocity, female crocodiles provide more care for their young than any other living group of reptiles.

GAVIAL
Gavialis gangeticus

Habitat	**Freshwater**
Number of Types	**One**
Degree of Danger	**Harmless**

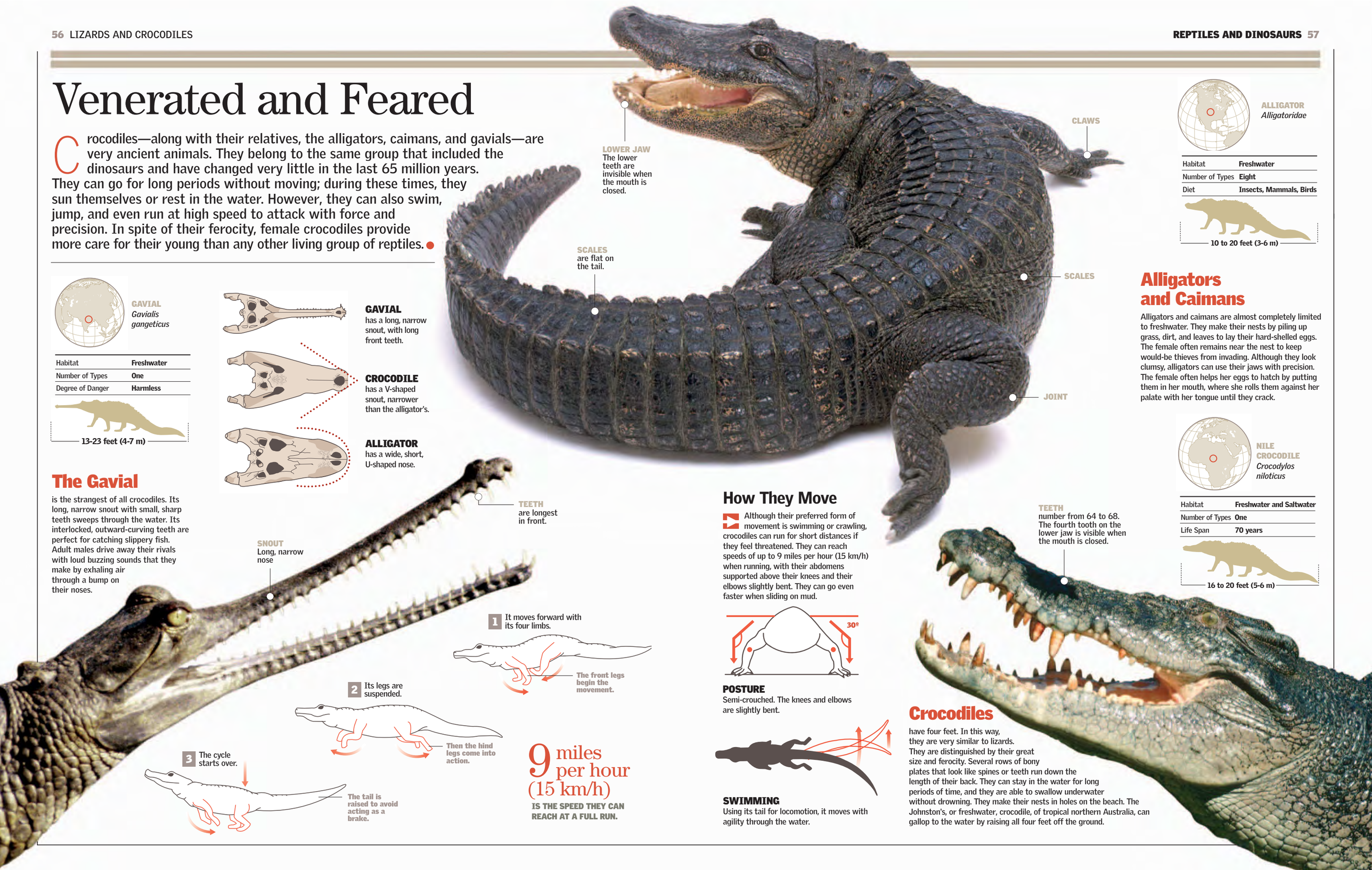
GAVIAL
has a long, narrow snout, with long front teeth.

CROCODILE
has a V-shaped snout, narrower than the alligator's.

ALLIGATOR
has a wide, short, U-shaped nose.

The Gavial

is the strangest of all crocodiles. Its long, narrow snout with small, sharp teeth sweeps through the water. Its interlocked, outward-curving teeth are perfect for catching slippery fish. Adult males drive away their rivals with loud buzzing sounds that they make by exhaling air through a bump on their noses.



9 miles per hour (15 km/h)
IS THE SPEED THEY CAN REACH AT A FULL RUN.

How They Move

Although their preferred form of movement is swimming or crawling, crocodiles can run for short distances if they feel threatened. They can reach speeds of up to 9 miles per hour (15 km/h) when running, with their abdomens supported above their knees and their elbows slightly bent. They can go even faster when sliding on mud.

POSTURE
Semi-crouched. The knees and elbows are slightly bent.

SWIMMING
Using its tail for locomotion, it moves with agility through the water.

ALLIGATOR
Alligatoridae

Habitat	**Freshwater**
Number of Types	**Eight**
Diet	**Insects, Mammals, Birds**

Alligators and Caimans

Alligators and caimans are almost completely limited to freshwater. They make their nests by piling up grass, dirt, and leaves to lay their hard-shelled eggs. The female often remains near the nest to keep would-be thieves from invading. Although they look clumsy, alligators can use their jaws with precision. The female often helps her eggs to hatch by putting them in her mouth, where she rolls them against her palate with her tongue until they crack.

NILE CROCODILE
Crocodylos niloticus

Habitat	**Freshwater and Saltwater**
Number of Types	**One**
Life Span	**70 years**

Crocodiles

have four feet. In this way, they are very similar to lizards. They are distinguished by their great size and ferocity. Several rows of bony plates that look like spines or teeth run down the length of their back. They can stay in the water for long periods of time, and they are able to swallow underwater without drowning. They make their nests in holes on the beach. The Johnston's, or freshwater, crocodile, of tropical northern Australia, can gallop to the water by raising all four feet off the ground.

The Largest on the Nile

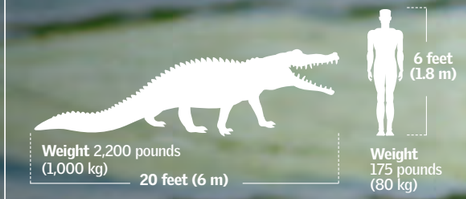
The impressive Nile crocodile is considered one of the most dangerous animals in Africa. It is one of three crocodile species that live in Africa and one of the largest species in the world. It can reach nearly 20 feet (6 m) in length and weigh over 2,200 pounds (1,000 kg). It lives in freshwater lakes and rivers. This dark olive-colored giant has a terrible reputation for devouring humans. For this reason, it has been both hated and revered, especially in ancient Egypt, where crocodiles were mummified and worshipped.

Range

Nile crocodiles live all along the Nile River and throughout sub-Saharan Africa. They are also found in ocean waters near the African continent and the island of Madagascar. They inhabit river deltas, lakes, large swamps, and estuaries and are currently raised in many countries, such as Kenya, Tanzania, Israel, Indonesia, France, Japan, and Spain.

NILE CROCODILE
Cocodrylus niloticus

Class	**Reptilia**
Length	**20 feet** (6 m)
Range	**Africa**
Weight	**2,200 pounds** (1,000 kg)



Habits

On land, crocodiles usually crawl on their bellies, although they can also raise their bodies and walk or run with their legs extended. Since they constantly need an external heat source, it is common to see them sunning themselves with their jaws open. This allows the breeze to cool the membranes of their mouths, regulating their body temperature. They are perfectly adapted for life in the water and use their tails for swimming.

Implacable Hunter

The Nile crocodile is a phenomenal predator. It can eat fish, antelope, zebras, and even buffalo. It can also jump out of the water to capture birds from their nests. In spite of their solitary habits, several crocodiles may join together to eat and work as a team to corral fish in shallow waters. They eat animals that approach the water's edge to drink by dragging them into the water to drown them and then tearing them to pieces.

1 Stalk

Using a stealth surprising because of its large size, the Nile crocodile stalks its prey until trapping it.

2 Attack

When hunting large prey, it attacks when they approach the water to drink.

3 Drown

Once it has the prey clenched in its jaws, it pulls it into the water and keeps it submerged until it drowns.

1 hour

THE AMOUNT OF TIME THEY CAN REMAIN UNDERWATER

Busy Females

The female lays from 16 to 80 eggs in a hole well above the water level. She will use this same nest throughout her life. She carefully protects the eggs while they incubate. When the young hatch, she carefully picks up the hatchlings and carries them to the water in groups. Mother and offspring stay together for six to eight weeks and then gradually separate.

HATCHLING
The young crocodiles will live in burrows up to 10 feet (3 m) long for the first four years of their lives.

The American Example

Caimans also belong to the order of crocodilians. These fierce reptiles live exclusively in the tropical regions of the Americas, mainly in lakes and swampy regions. Occasionally, when looking for food, they enter areas populated by humans. The caiman family includes the genera *Caiman*, *Melanosuchus*, and *Paleosuchus*. The largest species is the black caiman, so named because of the color of its hide.

Black Predator

The black caiman is distinguished from other caimans by dark stripes on the lower part of its mouth and yellow lines along the sides of its body. However, it is similar to other caimans in its feeding habits, which depend on its age. Young caimans feed on arthropods and amphibians, while adults eat fish, birds, and mammals, or snails if other foods are scarce. Caimans do not have a large appetite. For example, in captivity they consume only 14 ounces (400 g) of meat twice a week.

BLACK CAIMAN
Melanosuchus niger

Habitat	**Equatorial Amazon River**
Lifestyle	**Aquatic**
Length	**8-10 feet** (2.4-3 m)
Life Span	**30 years**

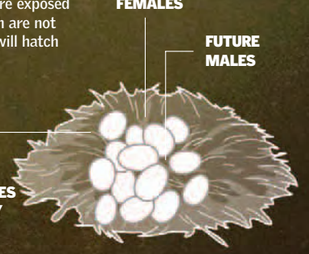
99% **DROP IN NUMBERS**
This species is in danger of extinction because of poaching.

Reproduction

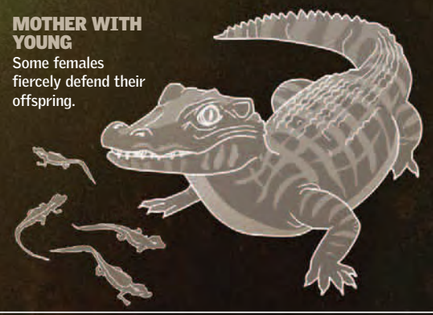
Caimans mate in the water. Once the eggs have been fertilized, the females begin to build their nest, forming a mound out of dry vegetation and earth. With their hind legs, they dig a hole in the center where they lay their eggs—from 30 to 75 at a time. When finished, they cover the nest with earth. In some cases, the females return to the water and have nothing more to do with the eggs.

Melanosuchus niger
BLACK CAIMAN

NEST
The eggs that are exposed to the air, which are not kept as warm, will hatch as females.



MOTHER WITH YOUNG
Some females fiercely defend their offspring.

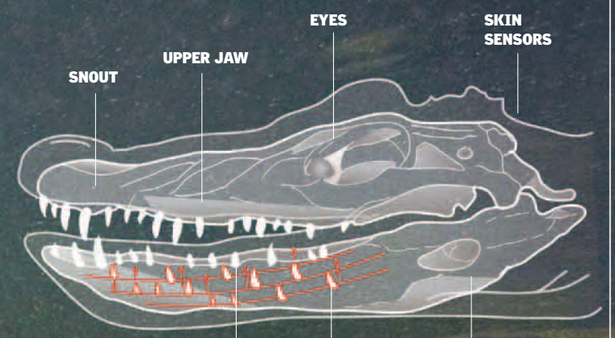


72 to 76 teeth

ARRANGEMENT OF TEETH
Caimans have five teeth in their upper front jaw, 13 to 14 in the rest of their upper jaw, and 18 to 19 in their lower jaw.

Large Mouthfuls

Caimans' teeth are not used for chewing or cutting but to trap, hold, and puncture the bodies of their prey. When a caiman's victim is large, such as a capybara or a wild boar, it twists its body in the water to tear off a chunk and swallow it. Caimans also hide their prey underwater to soften their body tissues. This makes it easier to rip off mouthfuls of flesh, which they swallow whole.



A Hard Life

In the state of Louisiana, a white alligator with no skin pigmentation lives in captivity. This trait would make it vulnerable in the wild, because it would be unable to absorb energy from the sun, a process that is crucial for many reasons, especially for the maintenance of its body temperature, allowing it to have enough energy to attack its prey.

ADULT SPECIMEN
Adults spend most of the day in the water. At night they come on shore to hunt.

Turtles and Snakes

GREEN TREE PYTHON
This tree-dwelling green python usually coils around a branch and waits with its head hanging down, ready to attack. It eats small mammals and birds.

SLOW BUT STEADY 64-65
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TURTLES IN THE WATER 68-69
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COBRAS 76-77
EGG EATERS 78-79

In this chapter, you will discover the amazing world of turtles and snakes. You will learn what they are like inside, where they live, and how they hunt their prey, as well as why some eat only eggs and others, such as constrictors (the most primitive snakes), have to suffocate their prey by coiling around it. This chapter will also reveal interesting facts about turtles' skeletons and shells (for example, turtles that swim have streamlined shells that enable them to glide easily through the water). Although people may think that turtles are peaceful creatures, many are actually carnivorous hunters that eat small invertebrates, fish, and even some larger animals.●

Slow but Steady

Since their appearance on Earth about 230 million years ago, turtles have changed very little. Turtles can live on land, in freshwater, or in saltwater. However, they all need light and heat to survive, and they all lay their eggs on land. Although aquatic turtles are nearly all carnivorous, some land-dwelling species are herbivorous. Turtles' most noticeable trait is their hard shell, which encloses and protects the soft part of their bodies. It also camouflages them for protection from predator species. ●

Freshwater Turtles

Most turtle species live in freshwater. They are distinguished by their feet, which are partially or totally webbed and are used for swimming, an activity at which they are highly skilled. They can also be identified by their shells, which are flatter than those of land-dwelling turtles. Some freshwater turtles are quite well adapted to living on land. In general, they prefer warm climates with abundant vegetation, so they commonly live near swamps and rivers located in subtropical areas around the world. Their shells may have particular characteristics depending on the species. The American box turtle, for example, can completely close its shell..

APPROXIMATELY
300-350
TURTLE SPECIES EXIST.

HEAD
has a pointed nose.

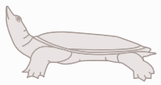
NECK
Much longer than that of other species

SHELL
This species has a very soft, thin shell.

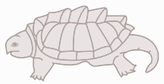
Chinese Soft-Shelled Turtle
Pelodiscus sinensis
They live in swamps and streams. Their diet consists of fish and mollusks.

TYPES OF SHELLS
Turtle shells differ according to each species' habitat.

STREAMLINED
Leatherback Turtle



FLAT
Red-Eared Slider



CRESTED
Alligator Snapping Turtle

Ocean Species

are the rarest. They live in warm waters and are excellent swimmers. They have flippers instead of feet. The front flippers move them forward, and the back flippers act as a rudder for steering. Their shells of oceanic turtles are flattened into a streamlined shape. These turtles have developed a dual respiratory system that allows them to remain submerged for up to two hours.

Hawksbill Turtle
Eretmochelys imbricata
Sea turtles are usually heavy and large. This Caribbean species can weigh up to 141 pounds (64 kg).

SHELL
Small, flat, and joined to the skeleton

Concealed from Danger

Many scientists believe that turtles' shells enabled them to survive long ago, during a time when so many other reptile species, including dinosaurs, perished. The shell consists of a domed back and a flat belly, joined by a bridge between the front and hind legs. The outer layer is made of skin and hornlike plates, and the inner layer is made of bone. Turtles draw their heads inside their shells in different ways depending on whether their necks are straight or side-bending. Land-dwelling turtles have shells that enable them to hide their legs, as well as their heads, inside, protecting their entire bodies from threats. The skeletons of ocean turtles, however, are completely integrated with their shells.

SIDE-NECKED TURTLE

Head
The neck bends to one side.

Legs and Tail
are always outside the shell.

STRAIGHT-NECKED TURTLE

Head
is pulled inside the shell by a vertical pendulum mechanism.

Legs and Tail
fold upward and are brought inside.

A Turtle's Age
Counting the successive hornlike plates that grow on the shell each year allows us to determine a turtle's age.

SHELL
Made of shieldlike plates

PLASTRON
Underside of the shell

Hermann's Tortoise
Testudo hermanni

On Solid Ground

Land-dwelling species have the best-protected legs because they are covered by large scales. They also have the most dome-shaped shells. Many species have front legs that are adapted for digging deep burrows, which serve as a shelter in inclement weather and protect them from threats from other species. The Florida gopher tortoise (*Gopherus polyphemus*) can dig tunnels up to 33 feet (10 m) deep. Some land-dwelling species can inflict very painful scratches.

Long-Lived Giants

Giant tortoises once lived on all the continents except Australia and Antarctica, both before and during the Pleistocene Era. They are now extinct on the continents and are only found on the Aldabra atoll in the Seychelles islands in the Indian Ocean and on the Galapagos Islands off the coast of Ecuador. In the Galapagos there are distinct populations living in different parts of its small area. The Galapagos giant tortoise, *Geochelone nigra*, is the largest tortoise in the world, weighing up to 880 pounds (400 kg). The oldest one still living is over 175 years old.

GALAPAGOS GIANT TORTOISE
Geochelone elephantopus

Habitat	Galapagos Islands
Diet	Herbivorous
Height	Up to 47 inches (120 cm)
Length	Up to 59 inches (150 cm)

LONESOME GEORGE is the nickname of the only survivor of a now extinct subspecies (*G. nigra abindoni*).

Almost 1,000 eggs

CAN BE LAID BY A FEMALE IN ONE SEASON. HOWEVER, VERY FEW YOUNG TORTOISES SURVIVE.

HUMPED BACK enables it to stretch its neck upward.

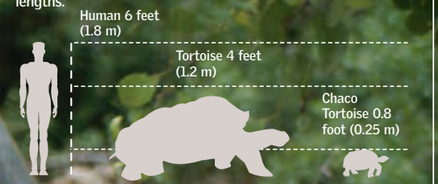
RETRACTABLE NECK enables it to hide its head inside its shell.

LONG NECK can reach the leaves of bushes.

SHELL weighs over 550 pounds (250 kg), enough to crush a human.

Giants

There are now 11 subspecies of Galapagos tortoises, including water-dwelling and land-dwelling varieties. All are in danger of extinction. They differ in maximum sizes, shell shapes, and neck lengths.



CLOSE RELATIVES
The Chaco tortoise *(Geochelone chilensis)* is a continental ancestor.

Almost 14 months

THE LENGTH OF TIME A TORTOISE CAN LIVE WITHOUT EATING OR DRINKING

PLATES are pointed, in the case of Asian tortoises.

BRIDGE joins the upper shell to the plastron.

FRONT LEGS are useful for climbing.

SCALES are typical of this order of reptiles.

CLAWS are used for digging.

The Life Cycle

Up to four months can pass between the time a new turtle is conceived and the time it hatches. Laying eggs takes several hours of work, and a female can lose up to 20 percent of her weight during this process. The large size of Galapagos tortoises makes them lazy; they spend most of their time sunning themselves in small groups on warm, dry volcanic soils near the coast or a swamp. Some eat carrion.

1
Reproduction
Mating
is rather aggressive; the male immobilizes the female in order to mount and fertilize her.

2
One to Two Months Later
Egg Laying
During the reproductive season, the female lays eggs every two weeks and makes from three to eight nests.

3
Two Months Later
Hatching
After hatching, the young climb to the surface, usually at night.

4
Five Years
Development
The animal reaches reproductive age, although it will keep growing throughout its life.

5
40 Years
Most Stable Size
After this point, its rate of growth slows.

Giant Egg
Its shell is hard and spherical.

Nesting

For nearly five hours, the female digs a funnel-shaped hole with her claws, softening the ground with her urine. She settles the eggs in layers, covers them with earth, and smoothes it down.

Main Predators

In addition to suffering from poaching humans in the past, Galapagos tortoises are in danger of extinction because of the low survival rate of their hatchlings, which are hunted by two types of species that have been introduced to their habitat: black rats and cats. Furthermore, the diet of adult female tortoises causes them to compete for food with goats and other livestock, more species not native to the tortoises' ecosystem.

ANIMALS INTRODUCED BY HUMANS

Turtles in the Water!

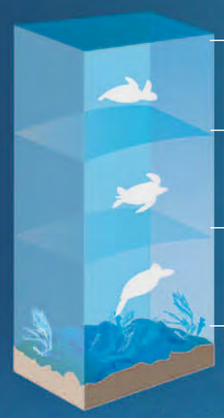
Sea turtles have had to adapt parts of their bodies to an aquatic environment. Their front legs propel them through the water, and their hind legs serve as rudders for steering. Their shells are highly streamlined. They can spend up to several hours submerged in the water, since they have a dual respiratory system. They lay eggs but make their nests on solid ground, and they have an interesting system for choosing the spot where their young will be born—they return to the same spot where they, themselves, were born.

GREEN SEA TURTLE
Chelonia mydas

Habitat	**Tropical and Subtropical Waters**
Diet	**Herbivorous**
Length	**Up to 39 inches (100 cm)**
Life Span	**50 years (estimated)**

Habitat

When winter arrives, sea turtles migrate in warm ocean currents, such as the Gulf Stream, to places with higher temperatures. However, they sometimes stay too long in these currents, which then vanish, leaving the turtles in frigid water.



DEPTHS
Using their flippers to make powerful strokes, sea turtles move through the water in a manner resembling flying.

1,500 pounds (680 kg)
The leatherback turtle can measure up to 9 feet (2.7 m) long and weigh up to 1,500 pounds (680 kg).

HEAD
is relatively large and cannot be retracted into the shell.

EYE
has a double pair of eyelids.

MODIFIED FEET
have become relatively large flippers.

FLIPPERS
Extension of the bones that make up the main part of the limb

BONY PLATES
are embedded in a thick, leathery, smooth skin, which gives the turtle the name leatherback. Its oily skin helps it to maintain its internal body temperature.

CLAW
Digit adapted for swimming

LEATHERBACK TURTLE
Dermochelys coriacea

Sizes

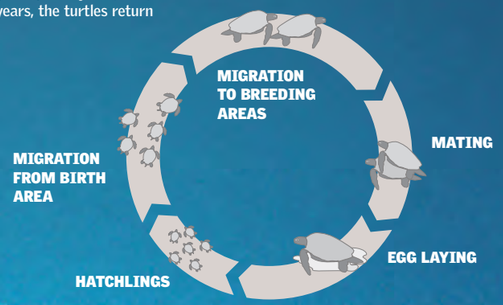
Sea turtles' measurements vary widely by species. The largest living species is the leatherback, and the smallest is Kemp's ridley.

GREEN SEA TURTLE SHELL

LEATHERBACK TURTLE SHELL

Reproduction

The reproductive cycle of sea turtles repeats every year, every two years, or every three years. Nesting is done during the summer on sandy beaches in tropical and subtropical areas where the average water temperature at the surface is always above 75° F (24° C). Every one, two, or three years, the turtles return from their feeding areas, which can be several hundred or even several thousand miles from their nesting sites. Apparently the turtles are able to memorize the exact location where they were born. They seem to navigate by ocean currents and temperatures.



SHELL
is aerodynamical in shape—convex on the upper side and nearly flat on the underside.

PLASTRON
consists of lateral shields that are gray or greenish-gray.

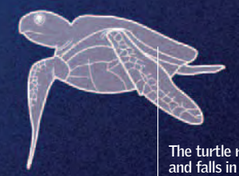
Breathing
Sea turtles have wedge-shaped lungs that lie underneath their shells and are attached to their backs along the spine. Sea turtles can also breathe through their skin.

22 miles per hour (35 km/h)
THE SWIMMING SPEED OF SEA TURTLES

Swimming

To be able to swim, turtles needed to adapt their front limbs and transform them into large flippers. Their hind limbs took the form of oars. They have a membrane around the bones of their phalanges (where their digits would be) and a shell that lies flat along their backs, giving them a streamlined shape.

The hind flippers are used as oars, pushing the turtle forward.



The turtle rises and falls in the water according to the rhythm of its flippers.

FLYING
The flippers give a powerful stroke that resembles flight as the turtles move through the water.

Internal Structure

Snakes are scaly reptiles with long bodies and no legs. Some are poisonous, but others are not. Like all reptiles, they have a spinal column and a skeletal structure composed of a system of vertebrae. The anatomical differences between species reveal information about their habitats and diets—climbing snakes are long and thin, burrowing snakes are shorter and thicker, and sea snakes have flat tails that they use as fins.

COLD-BLOODED
Their temperature varies according to the environment. They do not generate their own body heat.

HEART
The ventricle has an incomplete partition.

ESOPHAGUS

LUNG

LIVER
is long and located along the esophagus.

BLADDER

STOMACH

SPLEEN

SCALES
are generally found in the dorsal region.

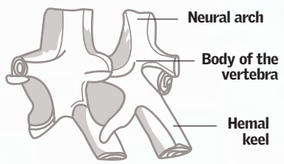
LARGE INTESTINE

EMERALD TREE BOA
Corallus caninus

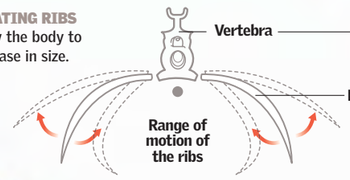
TREE BRANCH
Boas can change color to imitate the branch they are curled around.

THE SPINAL COLUMN
is composed of an assembly of jointed vertebrae with prolongations that protect the nerves and arteries. The system makes them enormously flexible.

VERTEBRAE



FLOATING RIBS
allow the body to increase in size.



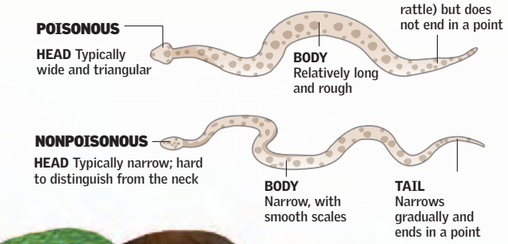
SMALL INTESTINE
is divided into a small tract and a large tract, which ends well before the tip of the tail.

SKIN
Many species of snake have no scales on the underside.

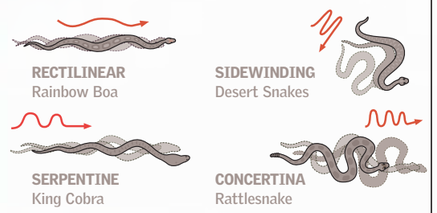
OVARIES
The female reproductive organs

REPRODUCTION
is sexual, and most species lay eggs. Some species give birth to live young.

IDENTIFICATION OF SOME POISONOUS AND NONPOISONOUS VIPERS



TYPES OF MOVEMENT DEPENDING ON HABITAT



"Blind" Snakes

Some subtropical and tropical snake species live underground and only come out in droughts or floods. These are the smallest snakes; some are no longer than 4 inches (10 cm). They have large heads, few teeth, and bodies covered in very soft, slippery scales, which enable them to slide into anthills and termite hills, their only sources of food. Their eyes, which are covered with scales, barely work.

Primitive Snakes

Boas and pythons were the first snake species to appear on Earth. Many have claws or spurs as vestiges of ancient limbs of their ancestors. They are not poisonous, but they are the largest and strongest snakes. They live in trees, and some, such as the anaconda—a South American boa—live in rivers.

33 feet (10 m)
LENGTH OF A PYTHON

Spotted Python
Antaresia maculosa
inhabits the forests of Australia.

400 vertebrae
THE NUMBER A SNAKE CAN HAVE

Sophisticated Snakes

Snakes of the family Viperidae, as well as other poisonous snakes that appeared later, have highly acute senses and a mouth apparatus with a system of retractable fangs for injecting venom.

INFRARED PITS
Snakes of the family Viperidae are distinguished by two thermoreceptive pits on either side of their heads, which enable them to sense differences in temperature. Some pits are extremely sensitive, helping the snake to gauge the size of its prey when it hunts at night.

2,978
SNAKE SPECIES EXIST.

GABOON VIPER
Bitis gabonica

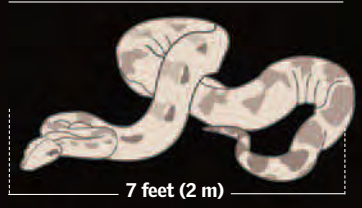
Deadly Embrace

Snakes have developed a wide range of techniques to kill their prey. For example, both boas and pythons are powerful constrictors, meaning that they kill by asphyxiating their prey rather than poisoning them with venom. Although boas and pythons belong to the same category of snakes (a category that includes the largest species in the world—the famous anaconda and reticulated python of Africa and Asia), their reproductive systems differ from one another. Their large size makes them heavy and slow moving, so they are easy prey for hunters, who kill them for their hides and meat.

AMAZON TREE BOA

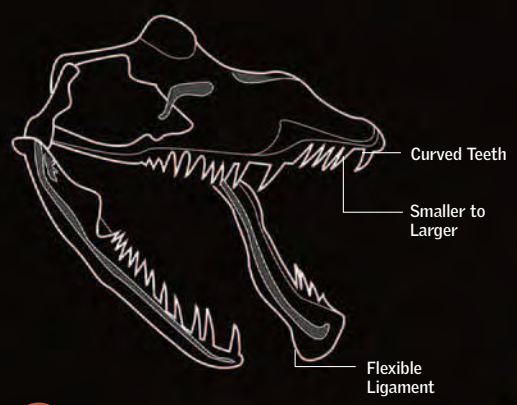
Corallus hortulanus

Range	South America
Habitat	Trees
Length	7 feet (2 m)



Tree Boa

can measure up to 7 feet (2 m) long and lives in trees. Its color blends in with the surrounding foliage, concealing it from predatory birds. Its prehensile tail holds firmly onto branches, while its head hangs down so that it can pounce on passing birds or mammals.



1 Teeth

The snake seeks out the head of its victim so that its prey will not be able to fight back. It takes the prey with its curving front teeth, keeping its victim from escaping. This enables it to suffocate its prey by coiling itself around the prey's body and squeezing (constricting).

JAWS
Snakes of the boa family (Boidae) have supraorbital and premaxillary bones.

TEETH
interlock.

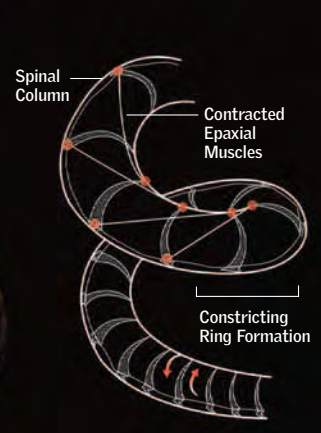
SCALES
Heat-sensitive

2 Constriction

The snake seeks the head of the prey to keep it from attacking. Its entire body surrounds its prey in a deadly embrace. Every time the victim breathes, the squeeze tightens. The prey dies of suffocation.

EPAXIAL MUSCLES CONTRACTED

EPAXIAL MUSCLES RELAXED



3 Widest Opening

When the prey is dead, the snake releases its grip and begins to feed. It swallows the head first and gradually releases the rest of the body from its coils. The time it takes to eat the prey depends on the animal's size and ranges from a few minutes to one or two hours.

The dead prey is ingested using the trunk muscles, which move the prey through the snake's body.

The skin stretches, and the scales separate.

33 feet (10 m)
THE LENGTH TO WHICH A GREEN ANACONDA *(Eunectes murinus)* CAN GROW

ovoviviparous
THIS IS HOW CONSTRICTORS REPRODUCE.

A Specialized Mouth

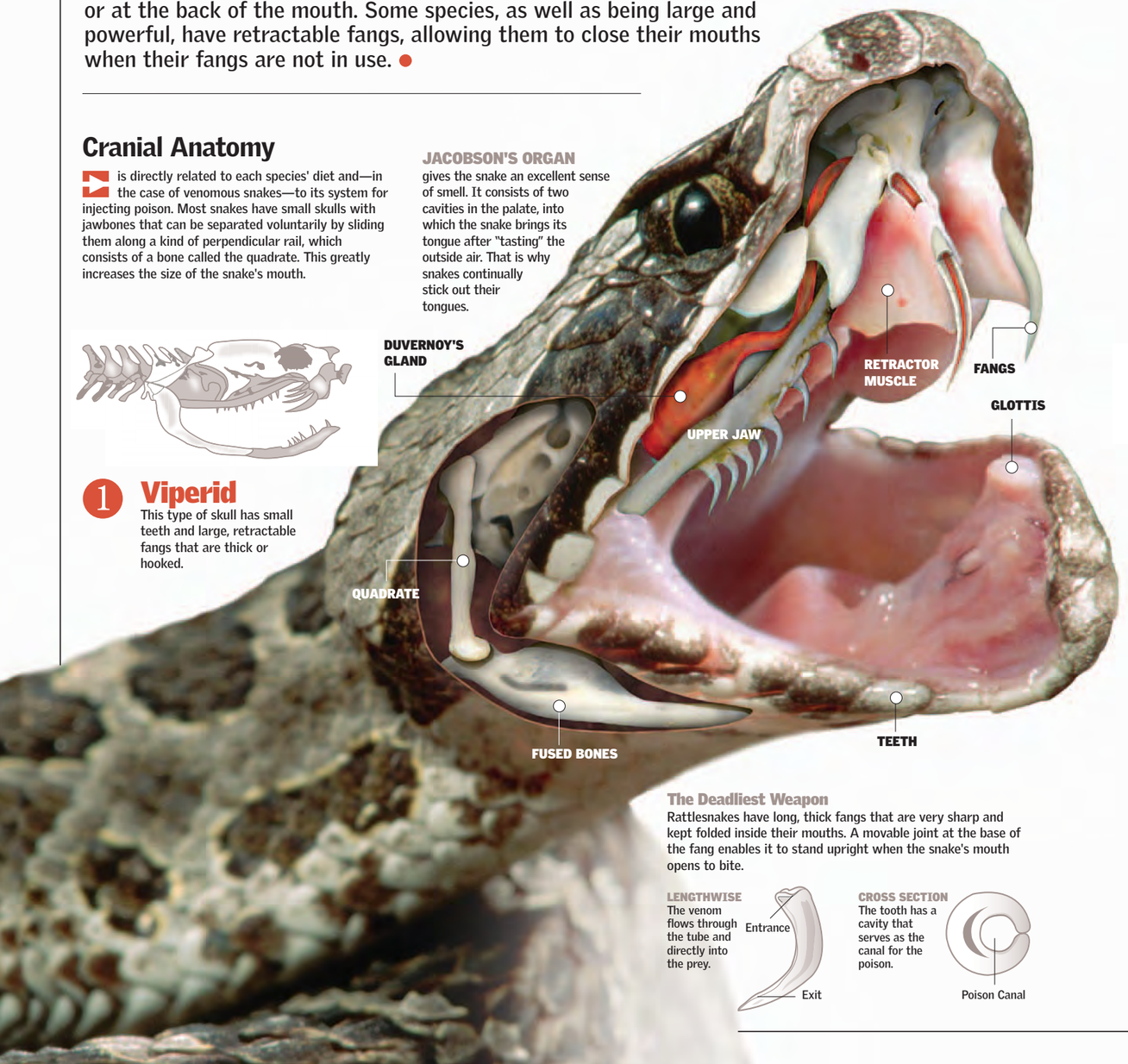
The most primitive snakes have heavy skulls and few teeth. Most snakes, however, have lighter skulls and jointed jawbones. These joints are loose and can easily become dislocated so that the snake can swallow prey larger than the natural shape of its own head. The teeth are fixed in the upper jaw or the palate, and the fangs for injecting venom may be located either at the front or at the back of the mouth. Some species, as well as being large and powerful, have retractable fangs, allowing them to close their mouths when their fangs are not in use.

Cranial Anatomy

is directly related to each species' diet and—in the case of venomous snakes—to its system for injecting poison. Most snakes have small skulls with jawbones that can be separated voluntarily by sliding them along a kind of perpendicular rail, which consists of a bone called the quadrate. This greatly increases the size of the snake's mouth.

JACOBSON'S ORGAN
gives the snake an excellent sense of smell. It consists of two cavities in the palate, into which the snake brings its tongue after "tasting" the outside air. That is why snakes continually stick out their tongues.

1 Viperid
This type of skull has small teeth and large, retractable fangs that are thick or hooked.



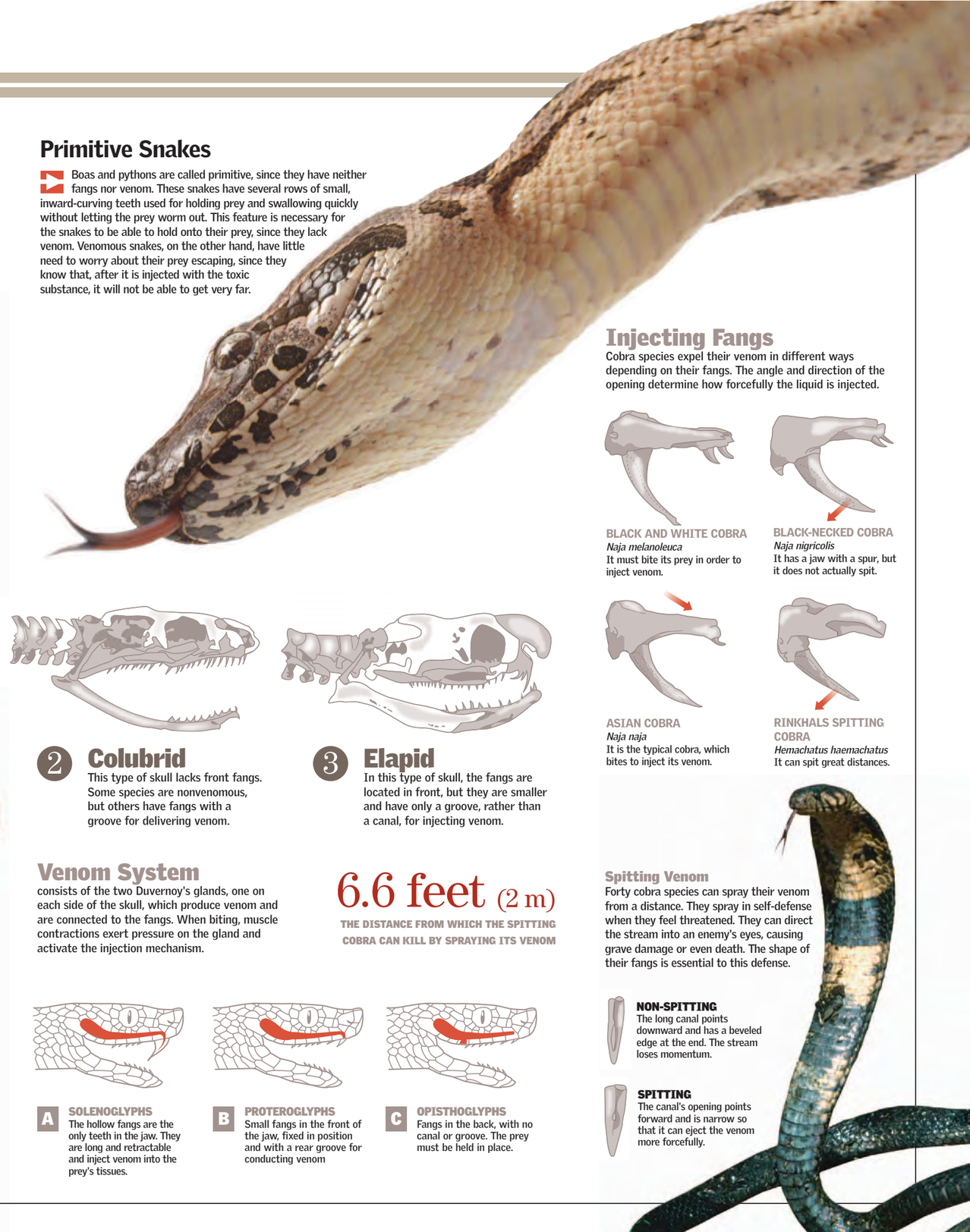
The Deadliest Weapon
Rattlesnakes have long, thick fangs that are very sharp and kept folded inside their mouths. A movable joint at the base of the fang enables it to stand upright when the snake's mouth opens to bite.

LENGTHWISE
The venom flows through the tube and directly into the prey.

CROSS SECTION
The tooth has a cavity that serves as the canal for the poison.

Primitive Snakes

Boas and pythons are called primitive, since they have neither fangs nor venom. These snakes have several rows of small, inward-curving teeth used for holding prey and swallowing quickly without letting the prey worm out. This feature is necessary for the snakes to be able to hold onto their prey, since they lack venom. Venomous snakes, on the other hand, have little need to worry about their prey escaping, since they know that, after it is injected with the toxic substance, it will not be able to get very far.



2 Colubrid
This type of skull lacks front fangs. Some species are nonvenomous, but others have fangs with a groove for delivering venom.

3 Elapid
In this type of skull, the fangs are located in front, but they are smaller and have only a groove, rather than a canal, for injecting venom.

Venom System
consists of the two Duvernoy's glands, one on each side of the skull, which produce venom and are connected to the fangs. When biting, muscle contractions exert pressure on the gland and activate the injection mechanism.

6.6 feet (2 m)
THE DISTANCE FROM WHICH THE SPITTING COBRA CAN KILL BY SPRAYING ITS VENOM

A SOLENOGLYPHS
The hollow fangs are the only teeth in the jaw. They are long and retractable and inject venom into the prey's tissues.

B PROTEROGLYPHS
Small fangs in the front of the jaw, fixed in position and with a rear groove for conducting venom

C OPISTHOGLYPHS
Fangs in the back, with no canal or groove. The prey must be held in place.

Injecting Fangs
Cobra species expel their venom in different ways depending on their fangs. The angle and direction of the opening determine how forcefully the liquid is injected.

BLACK AND WHITE COBRA
Naja melanoleuca
It must bite its prey in order to inject venom.

BLACK-NECKED COBRA
Naja nigricolis
It has a jaw with a spur, but it does not actually spit.

ASIAN COBRA
Naja naja
It is the typical cobra, which bites to inject its venom.

RINKHALS SPITTING COBRA
Hemachatus haemachatus
It can spit great distances.

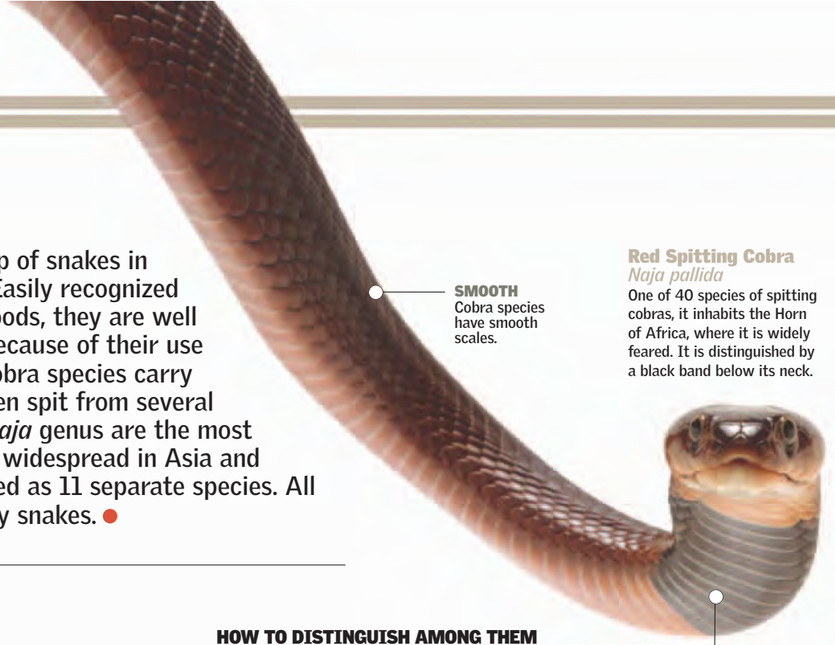
Spitting Venom
Forty cobra species can spray their venom from a distance. They spray in self-defense when they feel threatened. They can direct the stream into an enemy's eyes, causing grave damage or even death. The shape of their fangs is essential to this defense.

NON-SPITTING
The long canal points downward and has a beveled edge at the end. The stream loses momentum.

SPITTING
The canal's opening points forward and is narrow so that it can eject the venom more forcefully.

Cobras

Are an important group of snakes in the family Elapidae. Easily recognized by their outspread hoods, they are well known worldwide, mostly because of their use by snake charmers. Many cobra species carry deadly venom. Some can even spit from several yards away. Cobras of the *Naja* genus are the most widely recognized. They are widespread in Asia and were only recently recognized as 11 separate species. All are predatory; many eat only snakes.

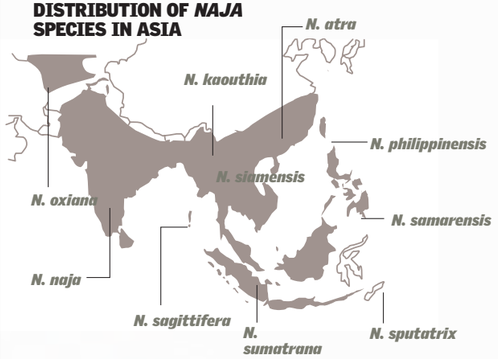


SMOOTH
Cobra species have smooth scales.

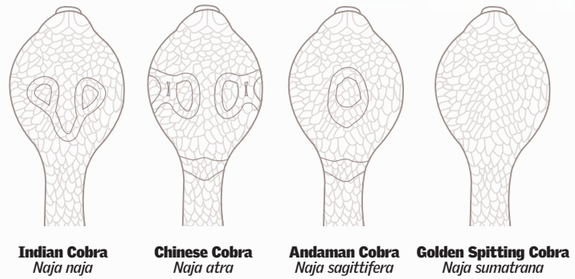
Red Spitting Cobra
Naja pallida
One of 40 species of spitting cobras, it inhabits the Horn of Africa, where it is widely feared. It is distinguished by a black band below its neck.

BLACK BAND
It sets this species apart.

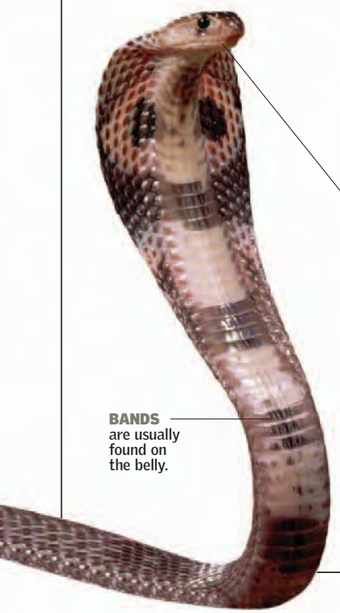
DISTRIBUTION OF *NAJA* SPECIES IN ASIA



HOW TO DISTINGUISH AMONG THEM
Although the Asian species look similar to one another, they often have distinguishing colors and scale patterns. The simplest way to identify them is by the pattern on their hoods—if you have time to look!



Indian Cobra *Naja naja*
Chinese Cobra *Naja atra*
Andaman Cobra *Naja sagittifera*
Golden Spitting Cobra *Naja sumatrana*



270
SPECIES OF ELAPIDS EXIST WORLDWIDE.

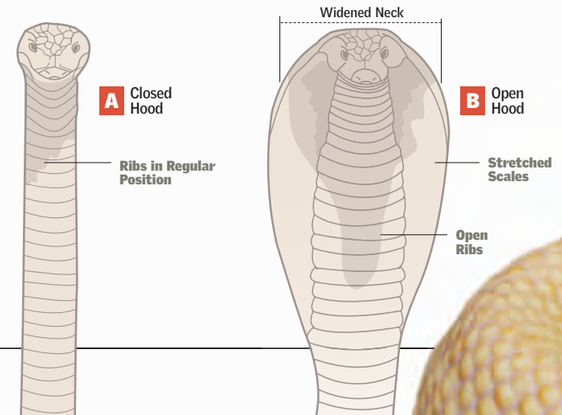
VENOM
is quite powerful. It paralyzes the muscles in minutes; the victim cannot flee and dies of cardiac arrest or asphyxiation.

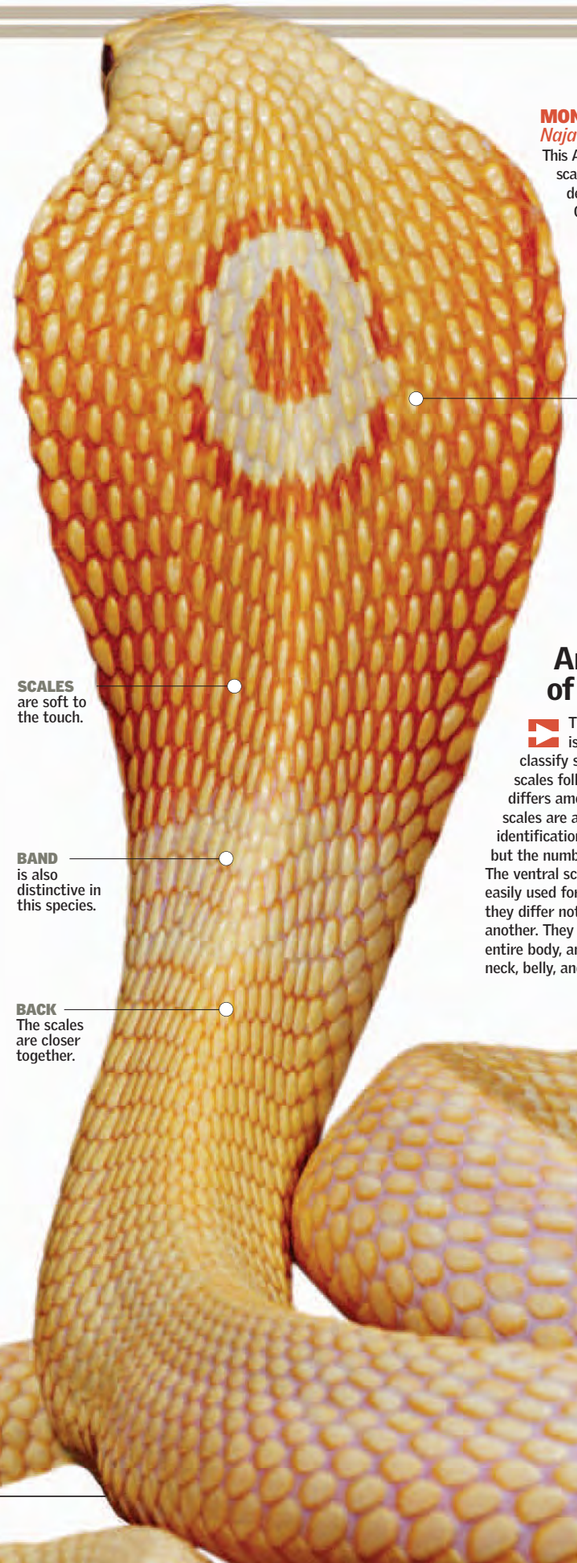
ASIAN COBRA
Naja naja
It is the most widespread species on the Indian subcontinent and one of the best known. Its distinctive trait is the mark on its hood, similar to a pair of glasses, which gives this snake its other name: spectacled cobra.

BANDS
are usually found on the belly.

The Hood

It is believed that when cobras feel threatened or are about to attack, they spread their hoods by widening their necks in order to look larger than they actually are. The mechanism involves the ribs, which are widened by the muscles that lie between them. When cobras put on this display, they are ready to strike. Some species also hiss while in this position.





MONOCLED COBRA
Naja kaouthia
This Asian species has soft scales. Its color varies widely depending on the region. One of its distinctive traits is the "monocle" on its hood, which gives it its common name.

MONOCLE
Made of two concentric rings, it is easily recognizable because of its white color.

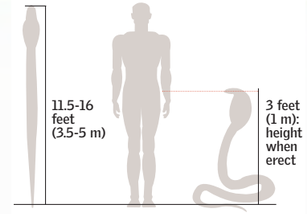
SCALES
are soft to the touch.

BAND
is also distinctive in this species.

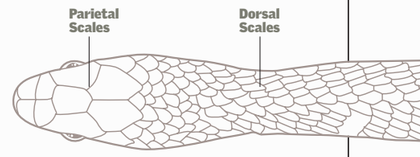
BACK
The scales are closer together.

Arrangement of Scales

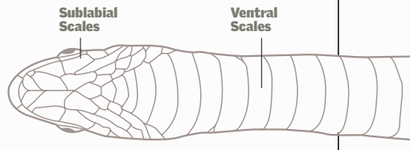
The appearance of the scales is a simple and easy way to classify species. The large parietal scales follow a line that usually differs among species. The sublabial scales are also widely used in identification. Usually there are five, but the number varies between species. The ventral scales are perhaps most easily used for identification, because they differ notably from one group to another. They are always wide, cover the entire body, and are divided into sections: neck, belly, and tail.



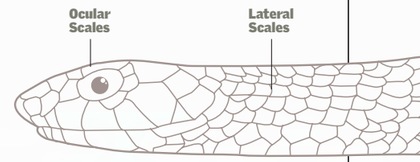
KING COBRA
Ophiophagus hannah
This is the largest cobra, measuring between 11.5 and 16 feet (3.5-5 m). It can attack backward and raise its head more than 3 feet (1 m) above the ground.



TOP VIEW



BOTTOM VIEW



PROFILE

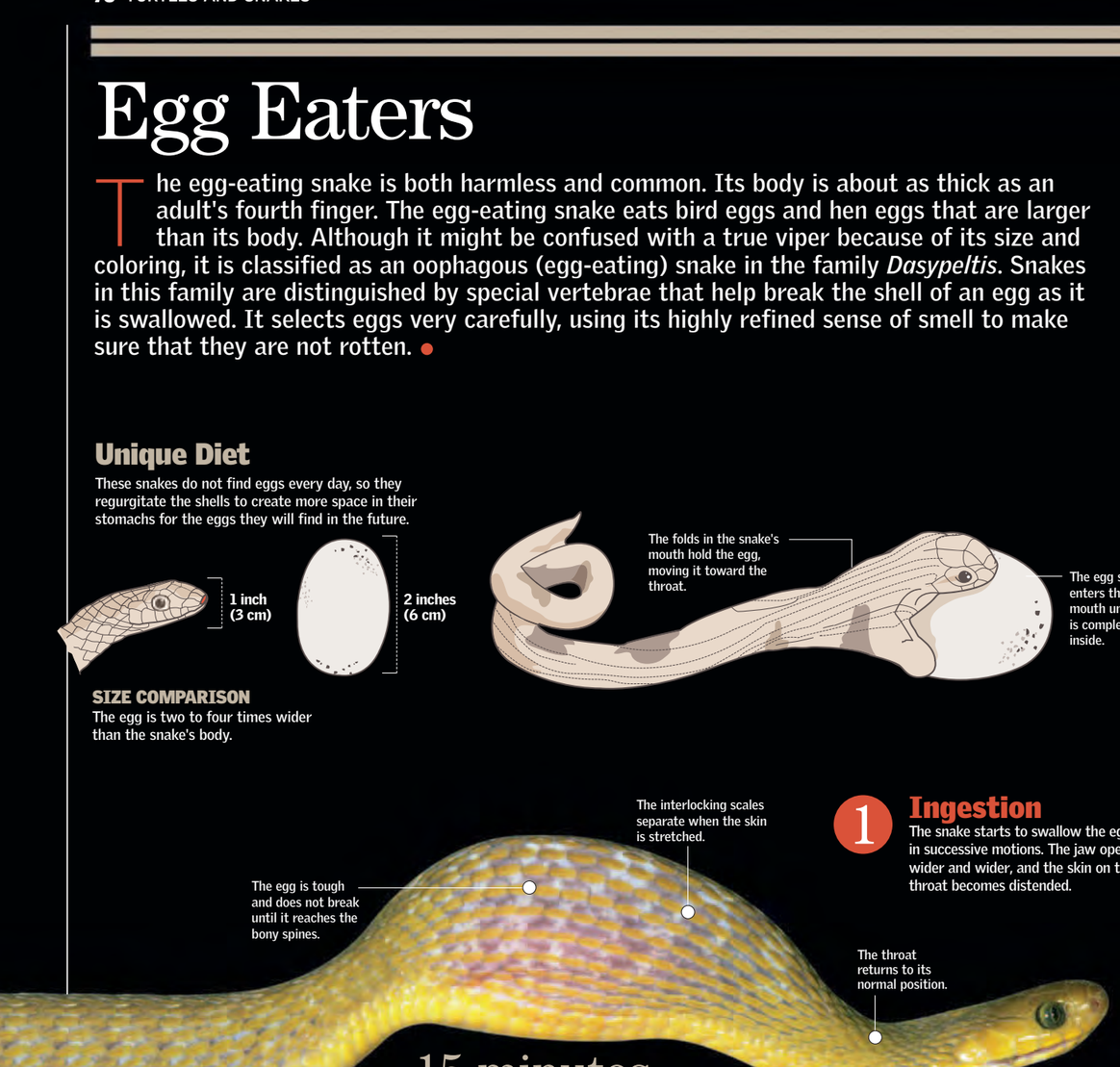
Egg Eaters

The egg-eating snake is both harmless and common. Its body is about as thick as an adult's fourth finger. The egg-eating snake eats bird eggs and hen eggs that are larger than its body. Although it might be confused with a true viper because of its size and coloring, it is classified as an oophagous (egg-eating) snake in the family *Dasypeltis*. Snakes in this family are distinguished by special vertebrae that help break the shell of an egg as it is swallowed. It selects eggs very carefully, using its highly refined sense of smell to make sure that they are not rotten.

Unique Diet

These snakes do not find eggs every day, so they regurgitate the shells to create more space in their stomachs for the eggs they will find in the future.

SIZE COMPARISON
The egg is two to four times wider than the snake's body.



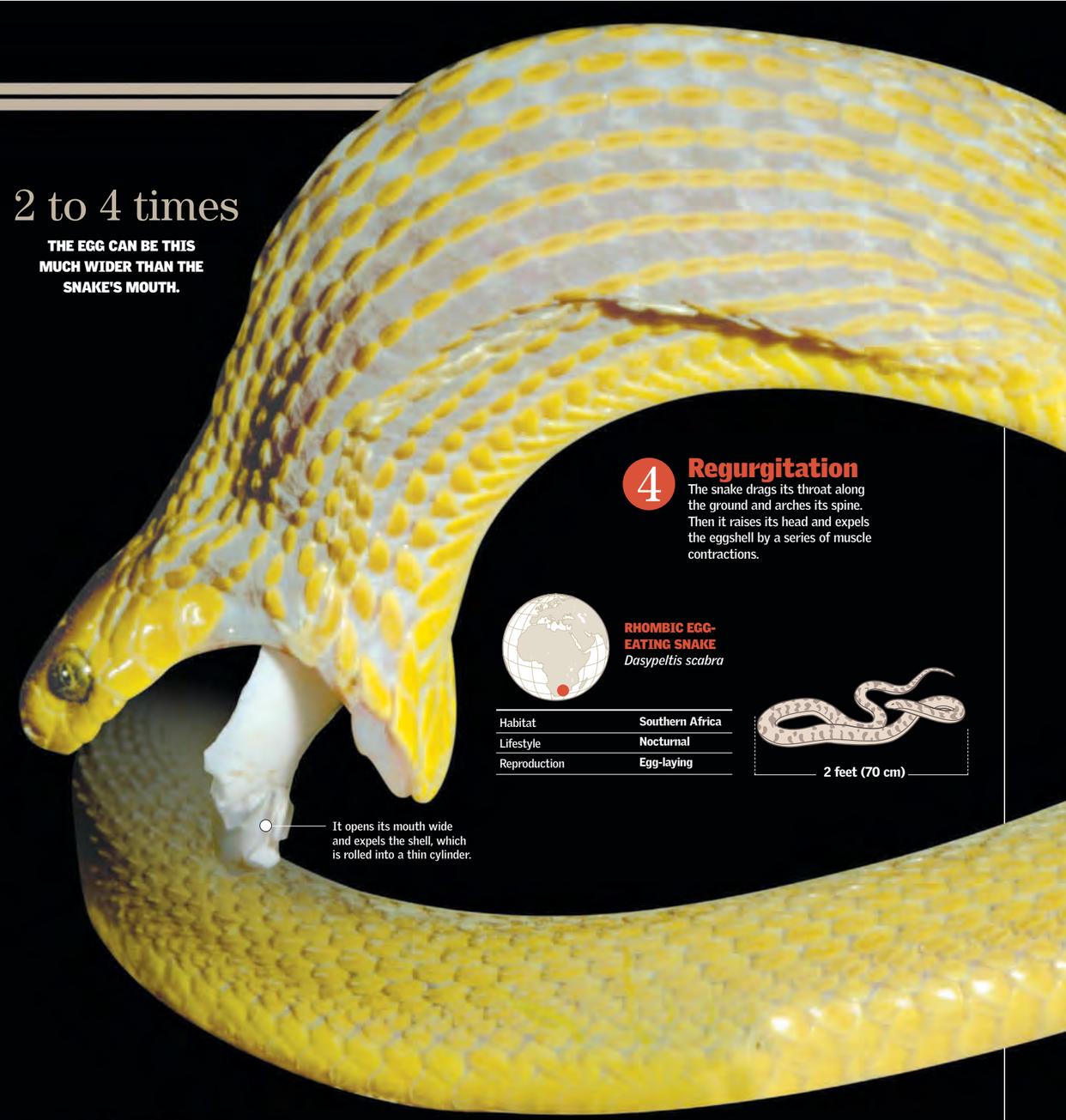
15 minutes
THE TIME IT TAKES TO SWALLOW AN EGG

1 Ingestion
The snake starts to swallow the egg in successive motions. The jaw opens wider and wider, and the skin on the throat becomes distended.

2 Rupture
The egg reaches the esophageal teeth, which puncture the eggshell; the head and neck muscles then crush it.

3 Pause
The food is processed in the digestive tract until the large bulge below the head disappears and the animal returns to its normal shape. It forces the eggshell back into its mouth.

2 to 4 times
THE EGG CAN BE THIS MUCH WIDER THAN THE SNAKE'S MOUTH.



4 Regurgitation
The snake drags its throat along the ground and arches its spine. Then it raises its head and expels the eggshell by a series of muscle contractions.

RHOMBIC EGG-EATING SNAKE
Dasypeltis scabra

Habitat	Southern Africa
Lifestyle	Nocturnal
Reproduction	Egg-laying

1 hour **THE TIME IT CAN TAKE TO REGURGITATE THE SHELL**

Dasypeltis
The name of the genus of egg-eating snakes. *Dasypeltis scabra* is usually gray or brown with darker marks below its back. It has teeth in its upper jaw, and only three to seven small, rudimentary teeth in the back of its jaw. Its teeth are no obstacle to ingesting enormous eggs.

Humans and Reptiles

MUSIC IN MARRAKESH
The snake charmers that live in the plaza of this city are famous and evoke scenes from the book *The Thousand and One Nights.*

HEROES AND VILLAINS 82-83
ENCHANTED SNAKES 84-85
ENDANGERED 86-87
DANGER: BAITS AND TRAPS 88-89
FEWER EACH TIME 90-91

Often feared by humans, snakes have long been the object of stories and myths; however, few people know what snakes are actually like. Since snakes are deaf, when they emerge from a charmer's basket, they are actually following the movement of the flute. Many snake species face extinction from persecution resulting from their dangerous reputation, their valued skins, and the desire of some to keep them as pets. Most snakes are beneficial to humans because they limit the spread of harmful animals like rats. ●

Heroes and Villains

Since time immemorial, reptiles have been the subjects of myths and legends. They have also earned their own space in religious texts, where they are depicted as gods or lesser beings. They may symbolize the incarnation of evil in some cases or divinity in others. The snake and the crocodile, among others, have taken on lives of their own; they play an active role in the stories of many peoples and have been assigned unique, culturally specific meanings.

RAINBOW SNAKE
Snakes hold a special meaning for the Australian Aborigines and have been depicted in myth both as the wind god and as the protector of people.

SNAKES
are what Medusa had on her head instead of hair.

MEDUSA
Legend says that those who looked into the eyes of Medusa would be turned to stone for eternity.

Religious Meaning

The toad, as a symbol in Christianity, appears to be directly related to deadly sins such as greed, lust, and gluttony. In Egypt, crocodiles were venerated, and valuable jewels were given in their honor. The snake is also mentioned in sacred Hebrew texts.

FIERCE
Aztec serpent from the 15th century, housed in the British Museum

QUETZALCÓATL
is the Nahuatl name for the Feathered Serpent. In the Aztec pantheon, Quetzalcóatl was the god of day, the creator of maize, the god of religious ceremonies, and the defender of priests.

SEBEK
was a god worshipped by the ancient Egyptians. He had the body of a human being and the head of a crocodile, and he was considered to be the creator of the Nile. It is said that he emerged from the waters of chaos during the creation of the world.

EVE
The snake is associated with trickery and treason in the Old Testament. It is the snake that incited Eve to enter into sin in the Garden of Eden by convincing her to eat forbidden fruit.

Range

Because they can be found virtually everywhere, reptiles have managed to infiltrate myths all over the world. They were venerated by the Inca and Aztec cultures in the Americas and were the object of legends in every corner of Asia. In China and Japan, the dragon with a snake's body represented earthly power, knowledge, and strength and was the bestower of health and good luck.

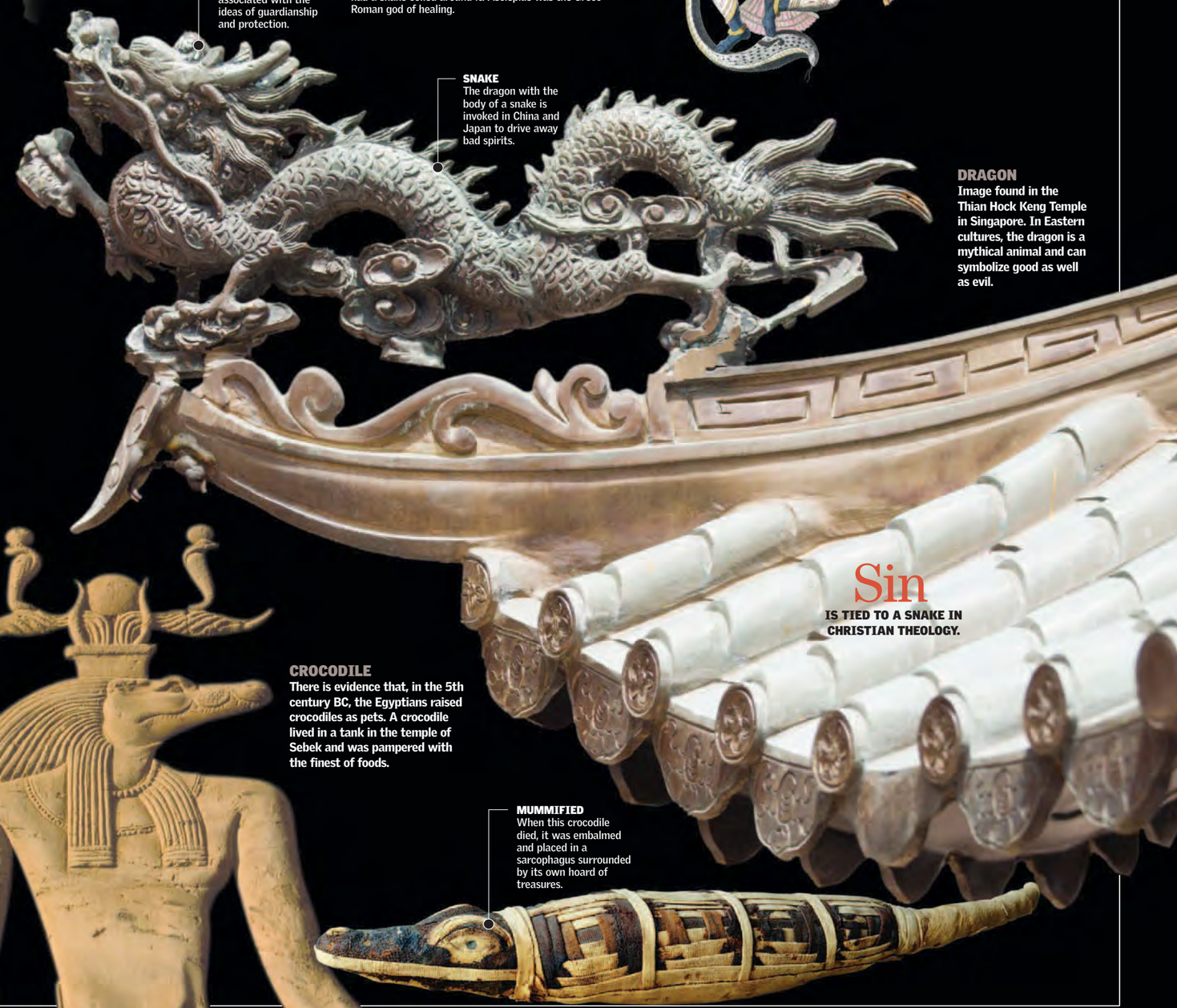
Representations

The engraving of a snake biting its tail to form a circle was the emblem of the so-called seal of Solomon that was used by theosophical societies. In Buddhism, the snake represents natural tendencies toward aggression. However, in medicine, it has long been associated with an ancient Greek symbol, the "rod of Asclepius," which had a snake coiled around it. Asclepius was the Greco-Roman god of healing.

DRAGON
In classical mythology, the dragon is associated with the ideas of guardianship and protection.

SNAKE
The dragon with the body of a snake is invoked in China and Japan to drive away bad spirits.

SIVA
Known in India as the god of destruction, Siva is depicted holding a snake around his neck.



DRAGON
Image found in the Thian Hock Keng Temple in Singapore. In Eastern cultures, the dragon is a mythical animal and can symbolize good as well as evil.

Sin
IS TIED TO A SNAKE IN CHRISTIAN THEOLOGY.

CROCODILE
There is evidence that, in the 5th century BC, the Egyptians raised crocodiles as pets. A crocodile lived in a tank in the temple of Sebek and was pampered with the finest of foods.

MUMMIFIED
When this crocodile died, it was embalmed and placed in a sarcophagus surrounded by its own hoard of treasures.

Enchanted Snakes

Cobras, as well as vipers and boas (to a lesser degree), are the object of the fascinating performances of snake charmers. In Asia—especially India—snake charmers carry out a very dramatic performance that has been repeated since ancient times. Snake charming has since spread all the way to the Mediterranean coast of Africa. The technique of enchanting snakes requires a knowledge of their weaknesses. For example, it is the movement of the flute, not its actual sound, to which they respond.

A Historical Practice

Revered since antiquity, the charming of snakes is a tradition that had its golden age during the period of imperial expansion, when the West colonized the East. Snake charmers were considered exotic, and they traveled the world and performed at fairs in large cities. They became veritable ambassadors of the East.

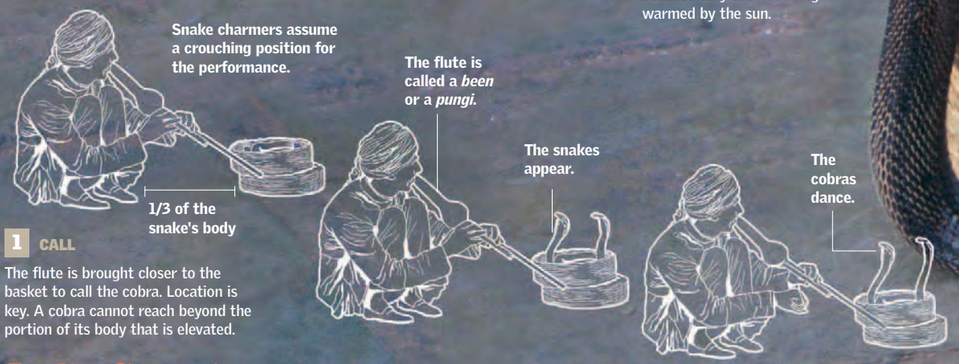
A FAMILY TRADITION
The practice of snake charming is passed from fathers to sons. In Bangladesh, charmers even form their own community; most are of Bedey ethnicity.

FLUTE
Its movement, not its sound, enchants the snake. Cobras, like all snakes, are deaf.

LOW ACTIVITY
The basket is kept in the shadows. This causes the snakes to be less active, because they are not being warmed by the sun.

SNAKES
Cobras are usually used, but vipers and even boas can serve as alternatives.

How They Do It



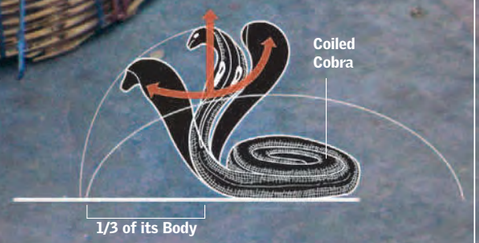
1 CALL
The flute is brought closer to the basket to call the cobra. Location is key. A cobra cannot reach beyond the portion of its body that is elevated.

2 EXIT
The movement of the flute incites the cobra to extend its body.

3 DANCE
At the moment of greatest bodily extension, the cobra performs a dance that climaxes with the snake charmer kissing it on the top of its head.

Cobras

Unlike vipers, cobras are not capable of striking from a coiled position. This keeps them from attacking beyond the reach of the extended portion of their bodies.

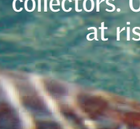


India Sanctions Snake Charming

In 2004, snake charmers in India were able to resume their jobs after having been accused of mistreating their animals during their shows.

Endangered

Marine turtles are in danger of extinction. Their need to leave the water to breathe makes them very easy to catch. Females and their offspring are at the greatest risk because they build exposed nests on the shore where they can easily be attacked by hunters and egg collectors. Others die when they are trapped in fishing nets. Marine turtles' nesting sites are also at risk because of the effects of coastal urbanization. Artificial light drives females from the routes they naturally take to lay their eggs. The offspring suffer from the same problem and become confused, unable to find their way.



LOGGERHEAD SEA TURTLE
Caretta caretta

Status	**Endangered**
Habitat	**Tropical Waters**
Size	**4 feet (120 cm)**

The loggerhead is a marine turtle that inhabits the coasts of tropical seas and can migrate great distances during its reproductive period. It lives in deep waters but is sometimes found near the shore. It is carnivorous but obtains food from a variety of sources depending on its age.

Migration

Some turtles travel great distances to reach the beaches where they will lay their eggs. The Laud turtle is capable of crossing the entire Atlantic Ocean.

HAWKSBILL TURTLE
Eretmochelys imbricata

Status	**Critical**
Habitat	**Warm Atlantic**
Size	**2 to 2.5 feet (60-80 cm)**

The hawksbill is one of the smallest sea turtles and is easily recognized by its shell, which has a central keel and toothed edges. The beautiful designs on their shells have caused this species to be savagely hunted. Hawksbills have a long life span and migrate less than other marine species.

LEATHERBACK SEA TURTLE
Dermochelys coriacea

Status	**Endangered**
Habitat	**Tropical Waters**
Size	**4 to 6 feet (1.3-1.8 m)**

The leatherback, the largest marine turtle, is one of the world's foremost migratory animals: it routinely crosses the Atlantic Ocean. The beaches where they nest and lay their eggs are now threatened by development related to tourism.

MESOAMERICAN RIVER TURTLE
Dermatemys mawii

Status	**Endangered**
Habitat	**Central America and Mexico**
Size	**1.5 to 2 feet (50-65 cm)**

Although turtles have developed adaptations for swimming, such as palm-shaped feet and a hydrodynamic shell, they are practically defenseless on land. They have very short tails, and the females have olive green coloring on the upper portions of their heads. They lay between six and 20 eggs in the marshy banks of rivers and are hunted by coypu (nutria) and humans.

GREEN SEA TURTLE
Chelonia mydas

Status	**Endangered**
Habitat	**Tropical Waters**
Size	**3 feet (1 m)**

The green sea turtle is one of the most common sea turtles. It is found in tropical and subtropical waters around the world. It has been a primary victim of commercial fishing. Green sea turtles are also in peril because of changing conditions on the beaches where they mate.

PACIFIC RIDLEY
Lepidochelys olivacea

Status	**Endangered**
Habitat	**Gulf of Mexico**
Size	**1.5 to 2.5 feet (50-75 cm)**

The Pacific ridley (olive ridley) has a round-shaped greenish-gray shell with five costal scutes. Its mouth is beaklike, similar to that of a parrot, and its preferred diet consists of crustaceans and benthic mollusks. It is the smallest of the sea turtles and the species under the greatest threat of extinction.

PANCAKE TORTOISE
Malacochersus tornieri

Status	**Vulnerable**
Habitat	**East Africa**
Size	**5.5 to 7 inches (14-17 cm)**

The shell of the pancake tortoise is not only very flat but also very flexible because of the openings in the bone on its underside. This feature allows it to crawl into narrow cracks to escape from predatory birds and mammals. It can also squeeze itself into holes.

GALAPAGOS TORTOISE
Geochelone nigra

Status	**Vulnerable**
Habitat	**Galapagos Islands**
Size	**Up to 4 feet (1.2 m)**

The shell and other characteristics of these tortoises have evolved in distinctive manners according to the conditions of each island where the species is found—especially conditions of climate and nutrition. Many have developed overgrown extremities to reach their food. They can no longer be found on some islands.

YELLOW-MARGINED BOX TURTLE
Cuora flavomarginata

Status	**Endangered**
Habitat	**China, Taiwan**
Size	**8 inches (20 cm)**

The population of this turtle has decreased significantly in recent decades because of the expansion of agriculture. The population remaining in Taiwan has stabilized and now shows signs of recovery. Those in China, on the other hand, remain in great danger.

Danger: Baits and Traps

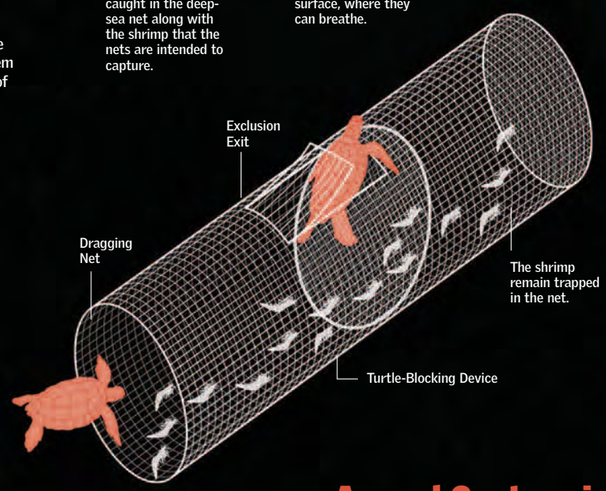
Sea turtles are in danger of extinction. During their migrations, they eat the bait set on hooks intended for tuna. As the turtles fight to free themselves from the hooks, they damage their internal organs and lose their buoyancy, which causes them to die from asphyxiation. Fishing nets are also mortal traps for sea turtles. Certain governmental and private organizations are seeking ways to reduce the danger for these turtles and their future offspring.

Turtle Excluder Devices (TED)

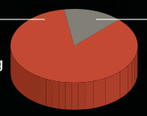
Sea turtles, such as the Laud, lay eggs on the Atlantic coasts of French Guiana and Suriname. They can only make it there, however, if they overcome the obstacle of deep fishing nets in the sea. To help them overcome this threat without interrupting the fishing of shrimp, nets have been developed with devices that exclude turtles from capture.

A **Capture**
The turtle swims in the ocean and is caught in the deep-sea net along with the shrimp that the nets are intended to capture.

B **Escape**
The turtles escape by swimming to the surface, where they can breathe.



TED EFFICIENCY



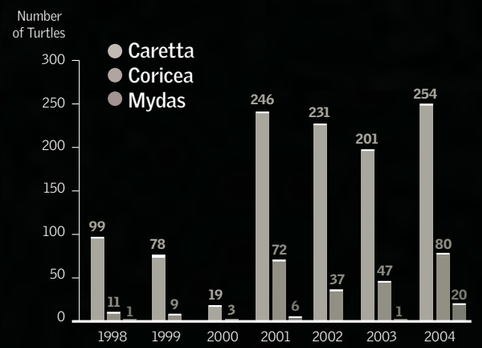
85% of turtles can escape from fishing nets using Turtle Excluder Devices.

15% escape only with difficulty or remain trapped.

PROTECTION FOR TURTLE EGGS

The presence of humans on beaches interferes with the development of turtle offspring. In order to preserve turtles, countries have joined forces with environmental nongovernmental organizations to carry out different tasks. In Suriname, people gather the eggs to protect them from illegal traffickers and corral the nests so that tourists do not destroy them. In the Caribbean basin of Costa Rica, Tortuguero National Park was established in the region home to the greatest amount of spawning green turtles.

Annual Capture in the Atlantic

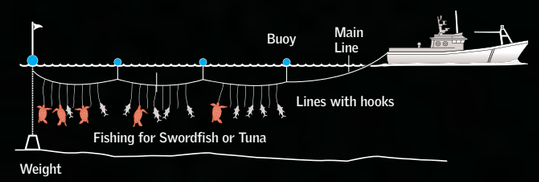


a 60 to 90%
reduction in captures has been achieved with the use of circular hooks.

Long-Line Fishing

Scavenging turtles eat bait. Because they cannot escape, they die of asphyxiation (lack of oxygen).

over 3,000
The number of hooks on a single main line



COMMERCIAL USES

Meat
Uncontrolled exploitation of turtles occurs to support massive consumption.

Shells
Tortoise shells are taken to produce jewels and decorations.

Turtles
Illegal trafficking arises from the demand for turtles as pets.

LONG HOOK
Turtles are able to swallow these hooks, which cause them to die of internal hemorrhaging or asphyxiation.

CIRCULAR HOOK
The greater width of these hooks reduces the chance of turtles being caught on them or swallowing them. Thanks to this modification, the numbers of turtles caught or injured has been dramatically reduced.

Fewer Each Time

Many species of reptiles are at serious risk of extinction—mostly because of habitat loss caused by human activities. The most threatened species with the fewest resources for recovery are those native to islands, which are unable to emigrate or adapt to rapidly changing conditions. Urban growth, deforestation, and water contamination are among the principal forces that have created this critical situation. Conscious of the problem, many countries have developed legislation to protect reptiles, but it is not always effective.

ARUBA ISLAND RATTLESNAKE
Crotalus unicolor

Status	Critical
Habitat	Aruba
Size	3 feet (95 cm)

This rare, little-known species of rattlesnake inhabits an area of Aruba of roughly 30 square miles (76 sq km). Its current status as a critically endangered species is mostly due to the loss of its ecosystem. Between 1993 and 2004, only 185 specimens were sighted in the wild. Arikok National Park is currently developing programs for the snake's conservation.

GOLDEN FER-DE-LANCE
Bothrops insularis

Status	Critical
Habitat	Brazil
Size	2.6 feet (80 cm)

This viper inhabits just one small island on the Brazilian coast, only 106 acres (43 ha) in size, called Queimada Grande. Deforestation is its main threat. Although the snake's population is stable, the loss of its natural habitat places it in critical danger of extinction.

ARUBA ISLAND RATTLESNAKE
Crotalus unicolor

BULGARDAGH VIPER
Vipera bulgardaghica

Status	Critical
Habitat	Turkey
Size	2.6 feet (80 cm)

This venomous, rodent-eating snake lives mostly in Anatolia. There its main threats are illegal trafficking and other human activities. Although awarded protected status in the region's animal preserves since 1994, it remains at serious risk of extinction.

FIJI CRESTED IGUANA
Brachylophus vitiensis

Status	Critical
Habitat	Fiji
Size	2.5 feet (75 cm)

The status of this species was last reviewed in 2003. It is distinguished by its rapid color changes and by the spiny crests on its back. It inhabits coastal forests, and its greatest threat is the introduction of goats to Fiji's islands. Since 1981, the island of Yaduataba has served as a primary sanctuary dedicated to its conservation. Nevertheless, the species continues to decline.

FIJI CRESTED IGUANA
Brachylophus vitiensis

Habitat Loss

THE LOSS OF HABITAT CAUSED BY HUMAN ACTIVITIES IS THE MAIN CAUSE OF REPTILE EXTINCTION.

HIERRO GIANT LIZARD
Gallotia simonyi

Status	Critical
Habitat	Canary Islands
Maximum Size	2 feet (60 cm)

This lizard inhabits the rocky outcroppings of El Hierro, one of the Canary Islands. Over recent decades, it was estimated that only 200 specimens remained, although the exact number is unknown. Its main cause of extinction is habitat loss and lack of food rising from competition with goats. Today these lizards are protected, and their numbers are recovering in preserves.

JAMAICA RACER
Alsophis ater

Status	Critical
Habitat	Jamaica
Size	2.8 feet (85 cm)

This reptile-eating snake inhabits the mountains of Jamaica. It is not venomous, and it is known for its great speed. Since 1994, it has been considered at critical risk of extinction because of habitat loss. Very few wild specimens have been sighted. Some experts believe that it may already be extinct.

TURKS AND CAICOS ROCK IGUANA
Cyclura carinata

Status	Critical
Habitat	Bahamas
Size	14 inches (36 cm)

Since the 1970s, nearly 13 subpopulations of iguanas have disappeared. Only one important species of this family of iguana remains, living in an area of 5 square miles (13 sq km) on a privately owned island. Its main threats come from predators introduced by humans and from habitat loss caused by urbanization.

CAPE DWARF CHAMELEON
Bradypodion pumilum

Status	Critical
Habitat	South Africa
Maximum Size	8 inches (20 cm)

This tiny, active chameleon is native to South Africa. As recently as a decade ago, it was commonly seen in thickets, in gardens, on plantations, and among crops. However, this species is currently at risk because of urban expansion. It is now only found on natural preserves.

CHINESE ALLIGATOR
Alligator sinensis

Status	Critical
Habitat	China
Maximun Size	6 feet (2 m)

This alligator inhabits the deep waters of the Yangtze River in China. Although its population is healthy in captivity, it is almost extinct in the wild. Today the Chinese government is developing a reintroduction program. Nevertheless, its future is uncertain.

Glossary

Adaptation

Trait of an organism's structure, physiology, or behavior that enables it to live in its environment.

Alkaline

Substances that increase the number of hydroxide ions (OH^-) in a solution; having a pH greater than 7; basic; opposite of acidic.

Amino Acid

Organic molecule containing nitrogen in the form of ammonia ($NH2^-$) and a carboxyl group ($COOH^-$) joined to the same carbon atom. They form the building blocks of protein molecules.

Amphibian

Group of animals that today includes frogs, toads, salamanders, and limbless caecilians.

Ancestor

Parent, grandparent, or more remote forebear that transmits certain genetic characteristics to its descendants.

Antidote

Substance that neutralizes the action of a specific poison.

Antipoisonous Serum

Specially prepared substance used to neutralize toxins from the bite of a specific snake in persons who show signs of poisoning.

Aorta

Main artery in blood circulation systems. It sends blood to other tissues of the body.

Biped

Animal that stands upright, walks, or runs using only the two hind limbs.

Carbon-14

Radioactive carbon isotope whose concentration can help determine the age of fossils.

Carboniferous

Geological period during the Paleozoic Era, which took place between 360 and 251 million years ago.

Carnivore

Animal that obtains its nutrients and energy by eating flesh.

Carrion Eater

Animal that eats the flesh of a dead animal.

Cellular Membrane

Flexible lipid envelope covering all living cells. It contains cytoplasm and regulates the interchange of water and gases with the environment.

Cerebellum

A section of the brain in vertebrates located above the brain stem and behind and below the cerebrum. It coordinates muscular activity and maintains balance.

Chelonia

Collective term for land and sea turtles.

Chordate

Animal that belongs to the phylum Chordata; any animal having a spinal cord, whether throughout its development or only in certain stages. Animals that are not chordates are called invertebrates.

Chromosome

Structure that carries the genes and, in eukaryotic cells, is composed of filaments of chromatin that contract during mitosis and meiosis.

Class

Taxonomic group above order and below phylum. For example, the class Reptilia, within the phylum Chordata, contains orders such as Squamata and suborders such as Sauria.

Cloaca

Exit chamber of the digestive tract of reptiles and birds. In some species, it also functions as the site of the reproductive and excretory systems.

Cold-blooded

Organism whose body temperature is mainly controlled by an external heat source because it has little capacity to generate its own heat through its metabolism.

Connective Tissue

Tissue that joins, supports, and protects the other three types of tissues: epithelial, muscular, and nervous. It contains a network composed of many fibers surrounding the cells.

Coprolite

Fossilized animal excrement.

Cytoplasm

Fluid within the cell membrane.

Dental Battery

Set of teeth joined together to form a cutting and grinding surface.

Dermis

Internal layer of skin, located under the epidermis.

Dewlap

Fold of skin hanging below the chin and extending to the chest in some lizards and other tetrapods. It can be unfolded in territorial battles to intimidate or to display certain moods.

DNA

Deoxyribonucleic acid. Double-helix shaped molecule that contains encoded genetic information.

Duvernoy's Glands

System possessed by some snakes for injecting venom. They are a pair of modified salivary glands, one on either side of the head.

Efferent

Nerve or blood vessel that flows from a central point toward peripheral tissues or organs.

Egg

Fertilized ovule that develops into a new individual. It usually also refers to the entire structure that covers and protects the fertilized ovule.

Embryo

The first stage of development of a multicellular animal or plant.

Estivation

State of extreme lethargy or inactivity caused by prolonged periods of drought or excessive heat.

Evolution

Changes in the gene pool of a population caused by processes such as mutation, natural selection, and genetic drift.

Family

Taxonomic category lower than order and higher than genus. The family Viperidae, for example, groups together the vipers.

Fertilization

The joining of a female sex cell with a male sex cell to form a diploid zygote.

Fossil

Remains of various types of ancient life-forms, both plants and animals, in a rocky substrate. They are found in the geological strata of the Earth's surface.

Fossilization

Process by which a deceased organism becomes a fossil over thousands of years.

Gastrolith

Stone found in the stomachs of certain herbivorous dinosaurs that helped them crush and digest food.

Gene

Unit of information in a chromosome; sequence of nucleotides in the DNA molecule that carries out a specific function.

Genetic Drift

Change in the frequency of alleles, the result of random processes.

Genus

Taxonomic category that includes species.

Gills

Respiratory organs of aquatic animals. Often an extension of fine tissues from the outer surface of the body or, in vertebrates, from part of the digestive tract.

Gland

Group of epithelial cells that produce secretions, organized inside a covering membrane to form an organ whose function is to synthesize and excrete molecules that the organ itself does not use.

Gonads

Glands that produce reproductive sex cells.

Gondwana

Ancient southern supercontinent that broke up 180 million years ago to form Africa, South America, Australia, Antarctica, and India.

Gregarious

Animal whose typical behavior, as a species, is conducive to living in groups.

Herbivore

Animal that feeds on grass or other plants.

Inflammation

Nonspecific defensive reaction of the body to the invasion of a foreign substance or organism, frequently accompanied by the accumulation of pus and an increase in the temperature of the affected area.

Jacobson's Organ

Organ on the upper part of the palate that takes in substances captured by a reptile's tongue and analyzes them to determine various characteristics of the object they come from. Also called the vomeronasal organ.

Lability

Fragility of an organ; sensitivity to potentially destructive agents.

Lamarck, Jean-Baptiste

French naturalist (1744-1829). He was the first to propose a theory to explain the changes in living beings.

Laurasia

Ancient northern supercontinent formed of North America, Europe, and Asia, excluding India.

Lipids

Group of water-insoluble substances, including fats, oils, waxes, steroids, glycolipids, phospholipids, and carotenes.

Mammals

Vertebrate animals whose females have mammary glands, which secrete substances that serve as food for their young.

Mass Extinction

Brief geological interval in which the extinction rate is greatly increased, affecting a large number of species and causing a considerable reduction of biodiversity.

Metabolism

The sum of all the physical and chemical transformations that occur within a cell or organism.

Mimicry

A superficial similarity in shape, color, or behavior on the part of certain organisms (mimetics) to others (models) or to objects in the environment for the purpose of hiding, seeking protection, or some other benefit.

Mitosis

Nuclear cell division, in which two daughter nuclei are formed that are identical to the parent nucleus.

Molars

Group of teeth that crush food within the mouth.

Molecular Clock

Marker used to estimate the evolutionary distance between two species. It is evaluated by comparing the gradual accumulation of amino acids between the proteins of those species.

Nucleic Acid

Molecule carrying the genetic information of a cell.

Omnivore

Animal that feeds on animal and plant species

Opisthoglyph

Group of snakes with fangs located in the back of the upper jaw and smaller teeth in front. The fangs can be smooth or have a groove on the surface that enables secretions to flow into the wound they produced.

Order

Taxonomic category below class and above suborder and family. For example, snakes and saurian reptiles belong to the order Squamata.

Ovary

Organ that produces eggs (female sex cells).

Oviparous

Animal that reproduces by laying eggs.

Ovoviviparous

Animal that reproduces by forming eggs that are carried, with soft shells, inside the female until they hatch. They may hatch inside the mother and come out as if they had been born live or be expelled from the egg pouch, breaking its membrane in order to hatch.

Ovum

A female haploid reproductive cell. It contains half as many chromosomes as the parent cell.

Parasite

Organism that lives at the expense of another and typically obtains nutrients that have already been processed by the host.

Parthenogenesis

Form of asexual reproduction in certain species, such as the gecko, in which the females produce young (all or mostly females) without the intervention of a male.

Pheromones

Chemical substances secreted by the reproductive glands of certain animals in order to attract individuals of the opposite sex.

Photoperiod

Relative length of night and day that enables organisms to measure the change of seasons and that influences their behavior and physiology.

Phylogeny

Evolutionary history of any taxonomic group. Usually represented as a branching tree.

Piscivore

Animal that eats only fish.

Plastron

Lower part of the shell of a turtle or tortoise.

Predator

Animal that captures and eats other animals as prey.

Protein

Macromolecule composed of one or more chains of amino acids. They define the physical characteristics of an organism and, when acting as enzymes, regulate chemical reactions.

Proteroglyph

System of fangs in cobras, mambas, coral snakes, and sea snakes; or the name referring to the group that contains these types of snakes. The fangs are located in the front of the upper jaw and are hollow or have a surface groove for carrying venom. They are relatively short and are fixed in an extended position.

Protractile

Describes a type of reptilian tongue that can be voluntarily hurled outward in an extremely rapid, precise movement.

Reabsorption

Process in which substances that are filtered or secreted by the kidneys and which are necessary for maintaining the organism's internal equilibrium are reincorporated into the plasma.

Reflex

Simple action of the nervous system that involves a sensory neuron, often one or more interneurons, and one or more motor neurons.

Sensory Receptors

Cells, tissues, or organs that detect internal or external stimuli.

Sexual Reproduction

Reproduction based on the fertilization of a female sex cell by a male sex cell, resulting in the production of descendants different from either parent.

Shedding

Sloughing off or change of skin, a process that happens naturally in many reptiles.

Smooth Muscle

Non-striated muscle that covers the walls of the hollow organs and arteries and is controlled involuntarily.

Solenoglyph

System of long, hollow fangs in some snakes or the name of the group that refers to snakes possessing this characteristic. The fangs are the only teeth in the upper jaw, and they pivot so that they lie flat along the roof of the mouth when the mouth is closed. They inject venom deep into the tissues of prey.

Species

Biological concept of a group of organisms that can or do interbreed in the wild and are reproductively isolated from other similar groups. This biological concept should be distinguished from the concept of a species as a category and as a taxon.

Sperm Cell

Mature male sex cell, which is typically mobile and smaller than the female sex cell.

Spinal Cord

Part of the central nervous system of vertebrates, surrounded by the spinal column.

Striated Muscle

Muscle tissue with a striped appearance that shows the arrangement of the contracting elements. Includes the voluntary skeletal muscle and the cardiac muscle.

Thalamus

Part of the prosencephalon of vertebrates located behind and below the cerebrum. It is the main connection center between the brain stem and the upper cerebral regions.

Thermoregulation

Ability of reptiles to change their body temperature by moving from a warm place to a cooler one or vice versa.

Tissue

Group of identical cells that carry out a common function.

Trophic Level

The position of a species in the food web or food chain.

Uric Acid

Water-insoluble nitrogenated waste product; the main component of the excrement of reptiles and insects.

Vertebrates

Animals with a spinal column that provides a structural axis and develops around the notochord, completely replacing it in most species.

Viviparous

Animal species whose females do not lay eggs and whose young are born live.

Warm-blooded

Organism whose main heat source is internal and is produced largely through oxidative metabolism.

Zoonosis

Illness transmitted by animals to humans.

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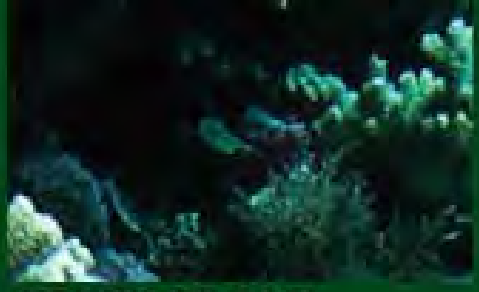

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Birds

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A Universe of Birds

Welcome to the world of birds. No matter how you approach it, this is a wonderful book not only for its pictures, splendid illustrations, size, and format but also because, as you read it, you will discover secrets about these inhabitants of the Earth, which, according to the history of evolution, came into being before humans. The text is written in a direct, easy-to-understand style. Most birds have a much-envied ability that has inspired poems and all types of experiments: they can fly. This enables them to see the Earth from afar, with its seas, mountains, rivers, cities, and other features. It has been estimated that more than 200 million birds migrate each year, all over the planet. Many of them fly thousands of miles, crossing desolate deserts and windy seas to arrive in Africa or Antarctica. Some find their way using the sun, the moon, and the stars; others follow their parents or use the course of rivers or mountain chains as references. In general, smaller birds migrating across continents stop several times to get food. It is surprising how fast they travel, in spite of these stops: it has been calculated that some small species cover almost 2,500 miles (4,000 km) in five or six days. Several studies have shown that carrier pigeons and white-headed sparrows, for example, can travel more than 600 miles (1,000 km) per day. Some ducks, such as the blue-winged teal, complete their trip from Canada to central Mexico in about 35 days, making several stops to feed along the way.

WHITE HERON *(Egretta alba)*
A species easy to distinguish in the proximity of rivers, lakes, and lagoons

Birds never cease to amaze us, whether hiding in trees, flying over high mountaintops, or nesting in Antarctica or on tall buildings. Perhaps the reason for such amazement is their behavior, which continues to be a mystery to human beings, as well as the differences among them. It is believed that there are approximately 9,700 living bird species in the world—more species than in any other vertebrate group except for fish. Once they reach adulthood, birds' weight varies from a mere 0.06 ounce (1.6 g), in the case of hummingbirds, to as much as 330 pounds (150 kg) for African ostriches. Even though most birds fly, there are some—such as kiwis, rheas, and ostriches—that run quickly on the ground. Some birds, being perfectly adapted to aquatic life, live in oceans, rivers, and lakes. The shape of their feet and bills varies according to the environment in which they live. Some aquatic species have bills modified to filter small water particles, whereas birds of prey have strong bent bills to hold down and tear apart their prey. What is the diet of birds based on? Because of their great diversity and wide distribution, their diets differ greatly. In general, birds eat a bit of everything, although insects are the most important element of their diet. They eat fruit, seeds, nectar, pollen, leaves, carrion, and other vertebrates. Most birds lay their eggs in nests. Worthy of mention is the protective attitude that both males and females have toward their young. Adult birds care for their chicks, warn and protect them against the danger of predators, and guide them to safe places where they can live and feed. We invite you to investigate up close the world of these fascinating beings that are able to run, climb, swim, dive, and cross the skies.

The Nature of Birds

OWL *(Bubo capensis)*
This owl is native to Africa. It feeds on birds and mammals.

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Many scientists maintain that birds descended from dinosaurs because fossils of dinosaur specimens with feathers have been found.

As a group, birds have exceptional eyesight—they have the largest eyes in relation to the size of their bodies. In addition, they have very light bones, which are suitable for flight. Just like their bills, birds' feet have also changed in accordance with the functions and particular needs of each species. For instance, walking birds—like other vertebrate groups—display a marked tendency toward having a reduced number of toes; ostriches, for example, have only two. Some birds of prey, such as eagles, have feet that are veritable hooks.●

Beyond Feathers

Defining what a bird is brings to mind an animal covered with feathers that has a toothless bill and anterior extremities morphed into wings. Other distinguishing characteristics are that they are warm-blooded and have pneumatic bones—bones filled with air chambers instead of marrow. Birds have very efficient circulatory and respiratory systems and great neuromuscular and sensory coordination. ●

Variety and Uniformity

We can find birds in every type of environment: aquatic, aerial, and terrestrial, in polar regions and in tropical zones. Their adaptation to the environment has been very successful. Nevertheless, birds are one of the groups that display the fewest differences among their members.

WINE-THROATED HUMMINGBIRD
0.06 ounce (1.6 g)
WEIGHT OF THE SMALLEST BIRD

AFRICAN OSTRICH
330 pounds (150 kg)
WEIGHT OF THE LARGEST BIRD

PENGUIN
-75 F (-60° C)
THE TEMPERATURE PENGUINS CAN ENDURE IN ANTARCTICA

WHITE-THROATED SPARROW
A small bird that lives in North America and on the Iberian Peninsula

Adaptation to Flying

Some crucial anatomic and physiological characteristics explain birds' ability to fly. Their bodies and feathers reduce friction with the air and improve lift. Their strong muscles, light bones, air sacs, and closed double circulatory system also play a role in their ability to fly.

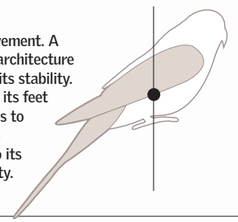
FEATHERS
Unique. No other living animal has them. They are appealing for their structure, variety, and constant renewal.

WINGS
propel, maintain, and guide birds during flight. They have modified bones and characteristic plumage.

105.8° F (41° C) IS THEIR BODY TEMPERATURE.

TAIL
The last vertebrae merge into the pygostyle. The tail feathers develop in this area.

STRUCTURE
Balance in movement. A bird's internal architecture contributes to its stability. The location of its feet and wings helps to concentrate its weight close to its center of gravity.



SENSES
Great visual acuteness and well-developed hearing

INNER EAR

EYE

NAPE

CREST

NOSTRILS

BILL
Originates in the epidermis. It is hard and resistant, with a consistency similar to that of horns. It grows continuously, like nails and feathers.

CHEST

COVERTS

FLIGHT FEATHERS

THORAX

ABDOMEN

THIGH

UNDERTAIL COVERTS

TARSUS

FEET
Birds walk on their toes. In general, they have three toes pointing forward and one pointing backward.

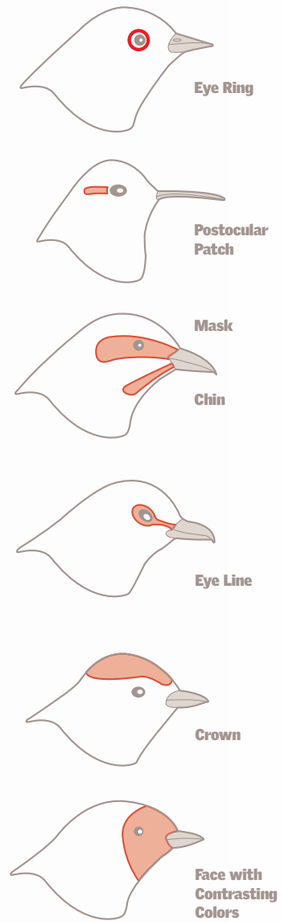
TOES

NAILS

High Metabolism
The high demands of flying are compensated by a high metabolic rate. Birds extract as many nutrients from food as they can.

IDENTIFICATION

There are differences in plumage and skin that make it possible to identify birds. The bill, because of its variations, also helps to establish bird groups.



SONGBIRDS

Passeriformes, or passerines, form the most numerous group among birds; they are characterized by a well-developed syrinx that enables them to emit harmonious songs and trills and by a soft plumage of varied colors. Because of their brain development, it is believed that passerines were the most recent birds to come into existence.

Origin

The evolution of birds is a debated theme in science. The most widespread theory states that birds descend from theropods, dinosaurs that walked on two legs. Fossils of dinosaur specimens with feathers have been found, but Archaeopteryx, a primitive bird that lived 150 million years ago, is the oldest relative known. Completely covered with feathers, it had a pair of wings that enabled it to fly. However, it retained many dinosaur traits.

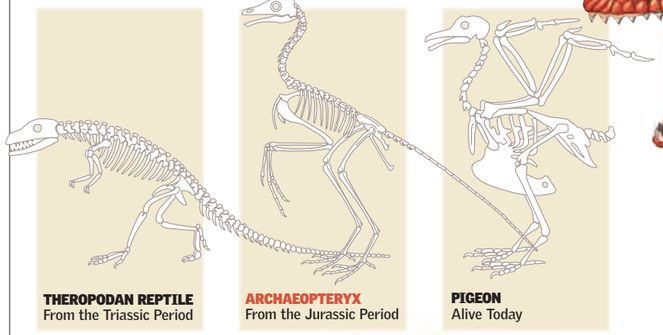
Archaeopteryx lithographica

lived in the Jurassic Period, 150 million years ago.

Comparison to a Human

Order	Saurischians
Suborder	Theropods
Diet	Carnivore
Length	10 inches (25 cm)
Height	8 to 12 inches (20-30 cm)
Weight	18 ounces (500 g)

From Reptile to Bird



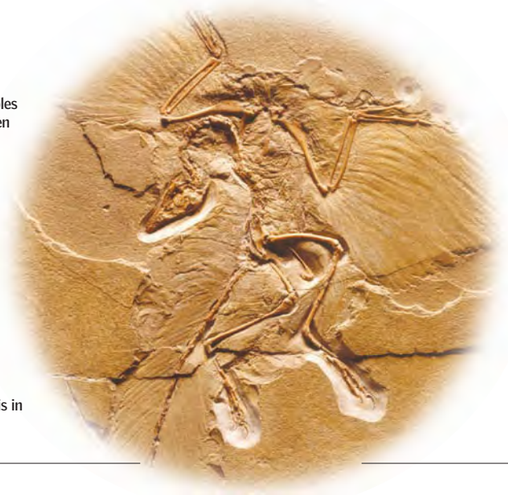
THEROPODAN REPTILE
From the Triassic Period

ARCHAEOPTERYX
From the Jurassic Period

PIGEON
Alive Today

Fossils

Several fossil samples were found between 1861 and 1993. The first one, found in Bavaria, Germany, was very important because its discovery coincided with the publication of *On the Origin of Species* by Charles Darwin, at a time when the search for evolutionary "missing links" fascinated scientists. The original is located in the British Museum. Another fossil, which includes the head, is in the Berlin Museum.



THREE TOES WITH TALONS
The hand has three extended fingers, each of which is equipped with a strong curved talon.

Talons for climbing trees

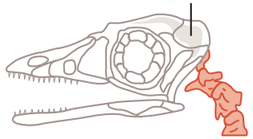
WRIST
Its wrist joint was more flexible than that of modern birds, a trait it shared with dinosaurs.

REPTILIAN JAWBONES WITH TEETH Unlike modern birds, it did not have a horn bill. There was a tight row of sharp teeth on each jawbone.

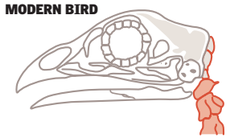
SPINE
Movable. The cervical vertebrae have a concave joint like that of the theropods, not a saddle-shaped one like that of birds.

SKULL
Similar to that of present-day reptiles and early theropods. The arrangement of the brain and ears reveals that it had a great sense of orientation and that it was able to perform complicated maneuvers.

ARCHAEOPTERYX Brain



MODERN BIRD



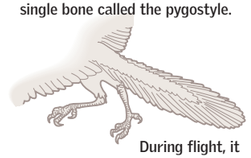
FURCULA
(Merged Collarbone) Shaped like a boomerang, as in many theropods

RIBS
Presence of ribs in the abdomen (gastralia), typical of reptiles and dinosaurs

SAURIAN PELVIS
Hip and femur of the archosaurian, not avian, type

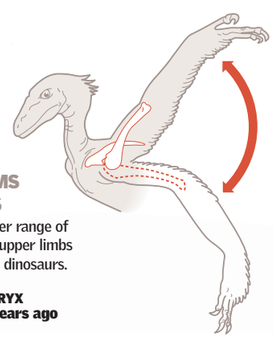
UNMERGED METATARSUS
In modern birds, the tarsus and metatarsus are fused into the tarsometatarsus.

VERTEBRATE TAIL
Composed of 21 or 22 pieces. Modern birds have tail vertebrae that are fused together into a single bone called the pygostyle.



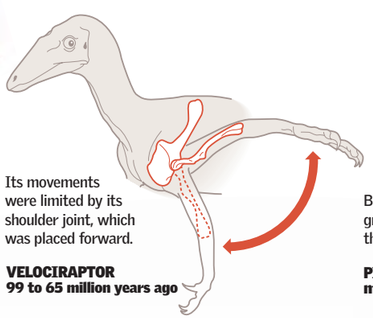
During flight, it functioned as a rudder. On the ground, it provided balance for walking.

TOES
The foot is functionally tridactyl. Its first toe (hallux), which usually points backward and typically does not touch the ground, is opposable, like that of modern birds (it can move in a direction perpendicular to toes II, III, and IV).



FROM ARMS TO WINGS
It had a greater range of motion in the upper limbs than primitive dinosaurs.

ARCHAEOPTERYX
150 million years ago



Its movements were limited by its shoulder joint, which was placed forward.

VELOCIRAPTOR
99 to 65 million years ago

Birds have greater mobility than Archaeopteryx

PIGEON
modern

ARCHAEOPTERYX LITHOGRAPHICA
Graphic Reconstruction

Skeleton and Musculature

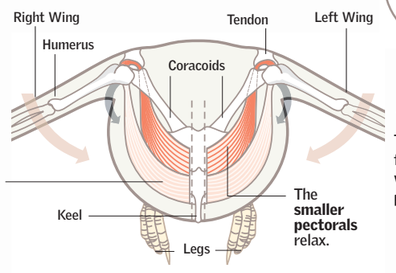
Both lightweight and resistant, the skeleton of birds underwent important changes in order to adapt to flight. Some bones, like those of the skull and wings, fused to become lighter. Birds have fewer bones than other vertebrates. Because their bones are hollow, containing internal air chambers, the total weight of their bones is less than that of their feathers. Birds' spines tend to be very flexible in the cervical region and rigid near the rib cage, where a large, curved frontal bone called the sternum attaches. The sternum features a large keel, to which the pectoral muscles attach. These large, strong muscles are used for flapping the wings. In contrast, running birds, such as ostriches, have more developed muscles in their legs.

Flapping Wings

Flying demands an enormous amount of energy and strength. Consequently, the muscles responsible for flapping the wings become very large, easily comprising 15 percent of the weight of a flying bird. Two pairs of pectorals, in which one muscle of the pair is bigger than the other, work to raise and lower the wings. They function symmetrically and in opposition to each other: when one contracts, the other relaxes. Their placement within the thoracic cavity corresponds roughly to the bird's center of gravity. The motion of the wings also requires strong tendons.

HUMMINGBIRD
Because of its adaptation to stationary flight, its pectoral muscles can account for 40 percent of its total weight.

DOWNWARD FLAP

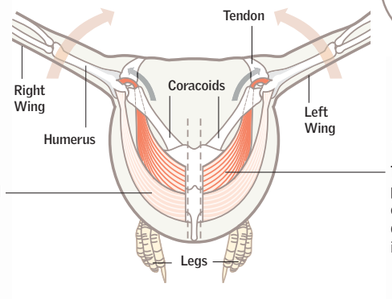


1. The **larger pectorals** contract.

2. The descending flapping of the wings takes place.

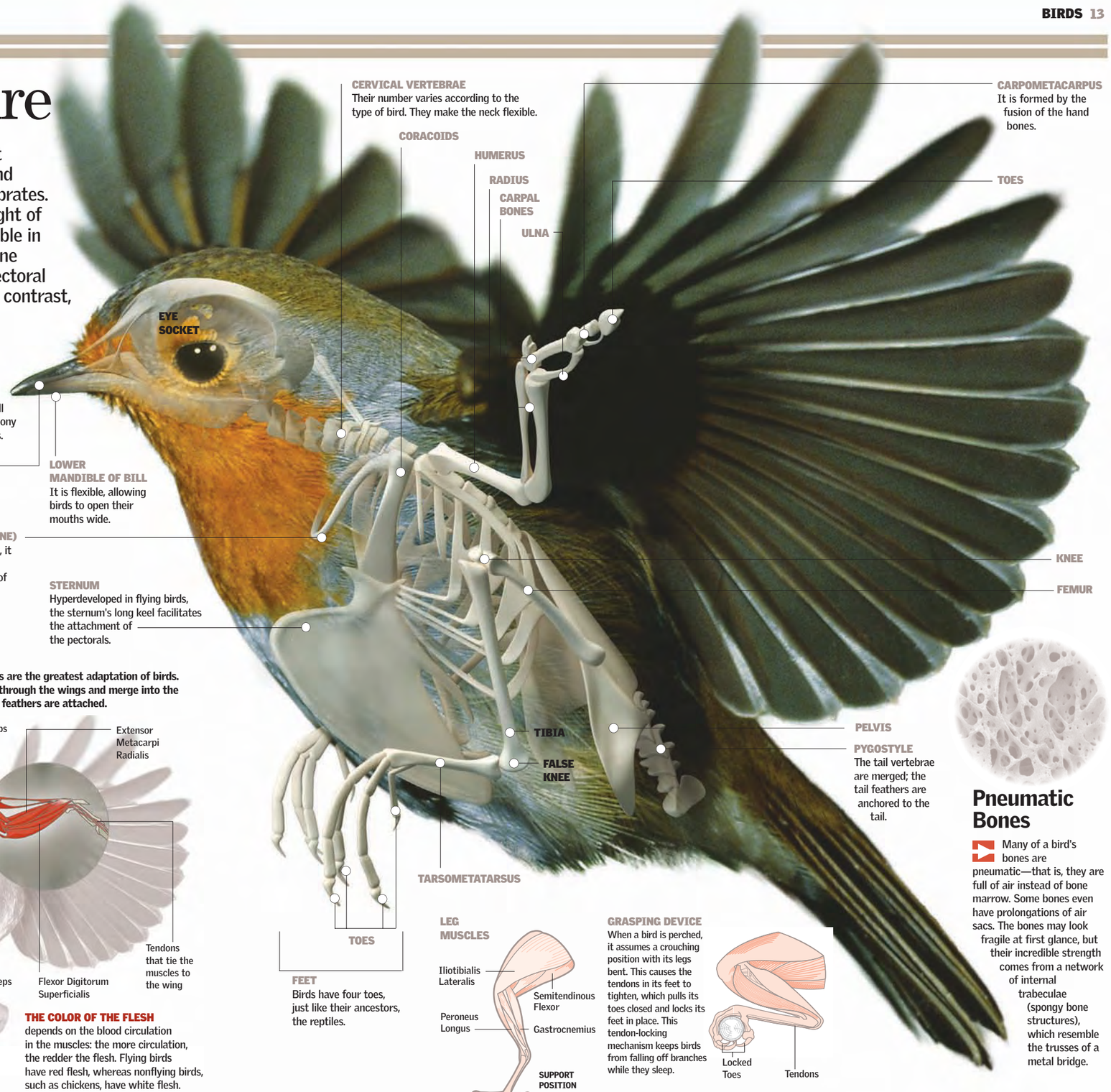
The **smaller pectorals** relax.

UPWARD FLAP



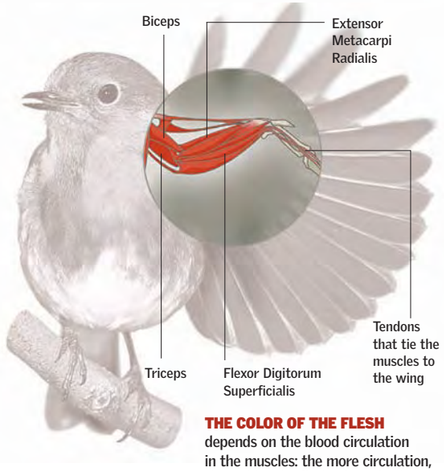
1. The **pectoral muscles** relax.

2. The **smaller pectorals** contract and draw the wings inward.



Wings

Without a doubt, wings are the greatest adaptation of birds. Strong tendons travel through the wings and merge into the hand bones, where the feathers are attached.



THE COLOR OF THE FLESH depends on the blood circulation in the muscles: the more circulation, the redder the flesh. Flying birds have red flesh, whereas nonflying birds, such as chickens, have white flesh.

Pneumatic Bones

Many of a bird's bones are pneumatic—that is, they are full of air instead of bone marrow. Some bones even have prolongations of air sacs. The bones may look fragile at first glance, but their incredible strength comes from a network of internal trabeculae (spongy bone structures), which resemble the trusses of a metal bridge.

Internal Organs

Birds in flight can consume oxygen at a rate that a well-trained athlete would not be able to withstand for even a few minutes. Because of this oxygen consumption, all their organs have had to adapt. The lungs of birds, though smaller than those of mammals of similar size, are much more efficient. Their lungs have several air sacs that both increase the efficiency of their respiratory systems and make them lighter. A special feature of the digestive system is a crop in the esophagus, where food is stored for digestion or for feeding the young. A bird's heart can be four times larger in relation to its body size than a human's in relation to its body size. ●

Digestive System

Birds have no teeth. They therefore ingest food without chewing, and their stomachs break it down. The stomach is divided into two parts: the glandular (or proventriculus) part, which secretes acids, and the muscular (or gizzard) part, whose muscular walls grind up what is eaten. In general, the process is very fast because flying requires a lot of energy, and the bird has to replenish that energy quickly. The digestive system ends at the cloaca, which is an excretory orifice shared with the urinary system. Birds absorb almost all the water they drink.

FOOD ITINERARY

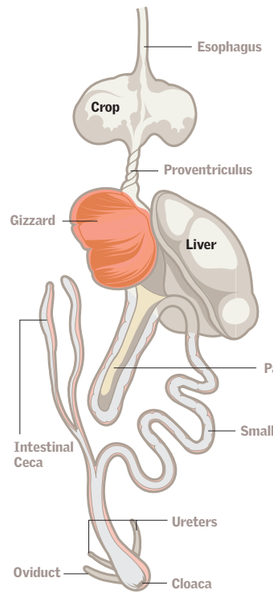
1 STORAGE
Some birds have a crop, which enables them to store food and digest it later. This way they decrease their exposure to predators.

2 PRODUCTION
The proventriculus secretes the gastric juices that initiate digestion.

3 BREAKDOWN
In the gizzard, a strong and muscular pouch, food is broken down with the help of swallowed stones or sand. The stones and sand play the role of teeth.

4 WATER ABSORPTION
occurs in the small intestine. Birds normally get water from the food they ingest.

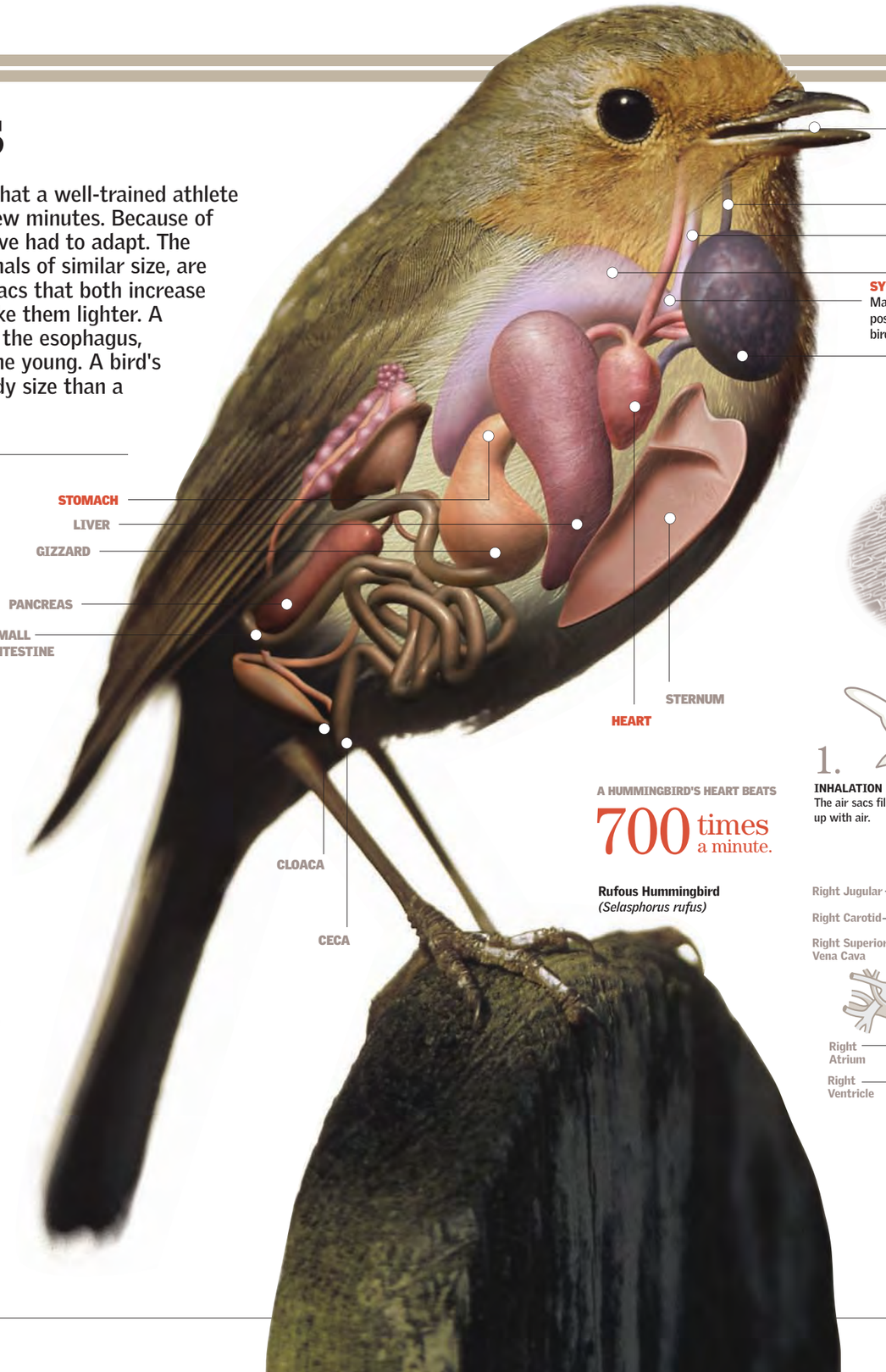
5 EXCRETION
The cloaca expels feces mixed with urine coming from the excretory system.



TYPES OF GIZZARD

Granivorous Birds have thick muscle walls and strong mucous membranes (or internal skin) to break down seeds.

Carnivorous Birds have thin muscle walls because digestion takes place in the proventriculus.



A HUMMINGBIRD'S HEART BEATS

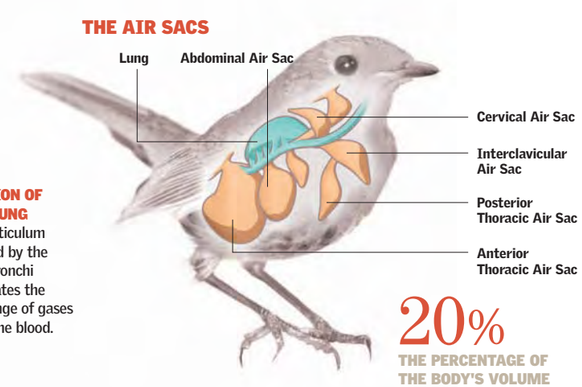
700 times a minute.

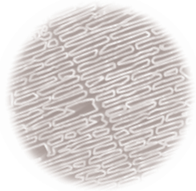
Rufous Hummingbird
(Selasphorus rufus)

Respiratory System

Birds have the most efficient respiratory system of any vertebrate because of the great effort that flying demands. It has two small, almost rigid lungs that are assisted by nine air sacs distributed throughout the body. The air sacs work as bellows, but they do not carry out gas exchange. Oxygen enters the bloodstream through the parabronchi, which are much like the alveoli in human lungs, in that they serve as the tissue for gas exchange. In the parabronchi, blood and air flow past each other in tiny passages. Because air flows in one direction through the lungs, and blood in the lung capillaries flows in the opposite direction, birds can make use of all the air they inhale, much like fish can with their gills and in contrast with mammals, which cannot.

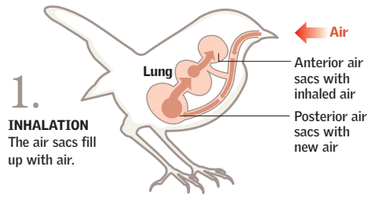
THE AIR SACS



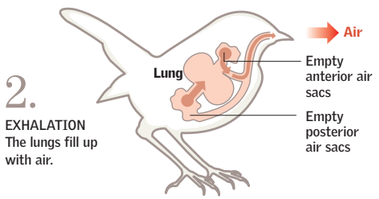


SECTION OF THE LUNG
The reticulum formed by the parabronchi facilitates the exchange of gases with the blood.

20%
THE PERCENTAGE OF THE BODY'S VOLUME TAKEN UP BY LUNGS AND AIR SACS



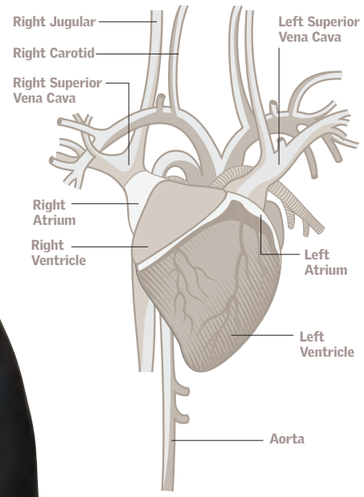
1. INHALATION
The air sacs fill up with air.



2. EXHALATION
The lungs fill up with air.

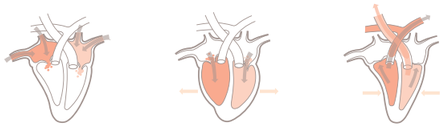
A Highly Complex Heart

Similar to that of reptiles, but having a heart with four chambers instead of three, the circulatory system distributes nutrients and oxygen throughout the body according to the body's needs. The heart's size and rate vary, depending on the bird's weight and activities. In general, bigger birds have smaller and slower hearts. For example, the heart of a seagull on the ground beats 130 times a minute; in flight, it beats 625 times a minute. A hummingbird's heart can beat 700 times a minute.



THE HEART'S ASYMMETRY

The left side of the heart is more developed, because it pumps blood to the whole body. The right side pumps blood only to the lungs.



1 The Blood enters through the right and left arteries.

2 Relaxed Ventricles They open the atrioventricular valves.

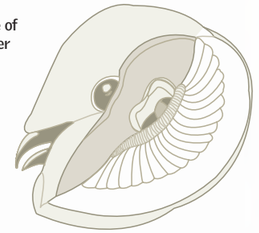
3 Contracted Ventricles The blood enters the bloodstream.

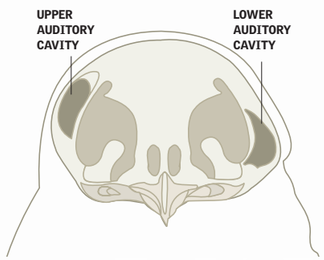
The Senses

In birds, the sense organs are concentrated on the head, except for the sense of touch, which is found all over the body. Birds have the largest eyes with respect to the size of their bodies. This enables them to see distant objects with considerable precision. Their field of vision is very broad, over 300 degrees, but in general they have little binocular vision. The ear—a simple orifice, but very refined in nocturnal hunters—helps them notice sounds inaudible to humans, which facilitates the detection of prey while flying. The senses of touch and smell, on the other hand, are important only to some birds, and the sense of taste is almost nonexistent. ●

The Ear

Birds' ears are simpler than those of mammals: a bird's ear has no outer portion, and in some cases it is covered with rigid feathers. A notable part of the ear is the columella—a bone that birds share with reptiles. The ear is nonetheless well developed, and birds have very acute hearing; whereas human beings can detect just one note, birds can detect many. The ear is essential to a bird's balance, a key factor in flying. It is also believed that in certain species the ear works as a barometer, indicating altitude.





LOCATION OF THE EARS

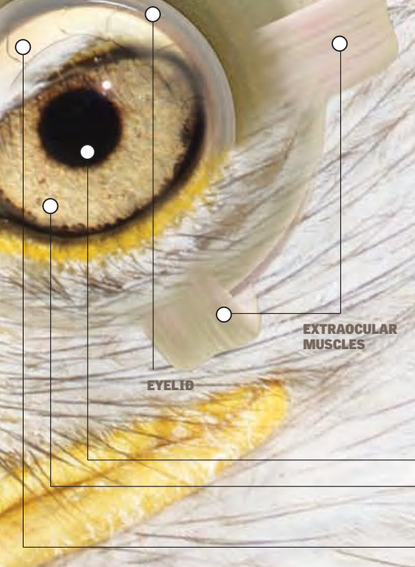
Located at different heights on the head, the ears cause the sense of hearing to occur with a slight delay. In nocturnal hunters, such as owls, this asymmetry allows for the triangulation of sounds and the tracking of prey with a minimal margin of error.

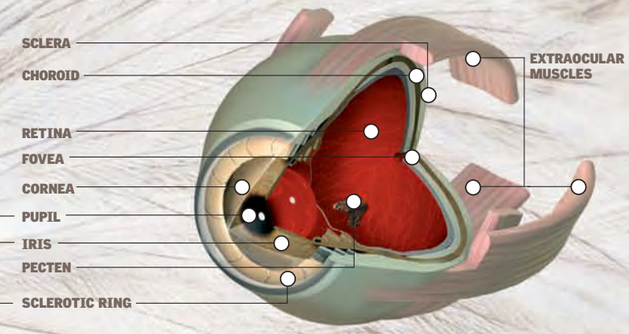
Touch, Taste, and Smell

The sense of touch is well developed in the bill and tongue of many birds, especially in those birds that use them to find food, such as shore birds and woodpeckers. Usually the tongue is narrow, with few taste buds, but they are sufficient to distinguish among salty, sweet, bitter, and acidic tastes. The sense of smell is not very developed: although the cavity is broad, the olfactory epithelium is reduced. In some birds, such as kiwis and scavengers (condors, for example), the olfactory epithelium is more developed.

Vision

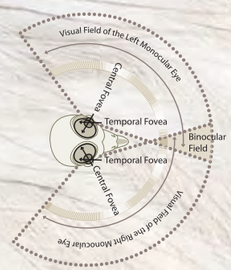
Is the most developed sense in birds because some flight maneuvers, as well as the recognition of food from afar, depend on it. Birds have relatively large eyes. In most cases, they are wider than they are deep because the lens and the cornea—which is supported by a series of sclerotic bony plates—project beyond the eye socket. In hunting birds, the eyes are almost tubular. The muscles around the eye change its shape, alter the lens, and create greater visual acuity: birds typically have a 20-fold magnification (and sometimes, as in the case of some diving birds, a 60-fold magnification), in comparison with humans. Their sensitivity to light is also remarkable, with some species being able to recognize light spectra invisible to the human eye.





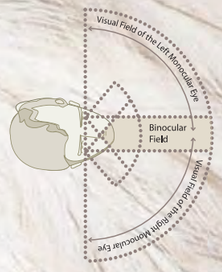
FIELD OF VISION

The eyes—when located on the sides of the head, as is the case with most birds—create a broad field of vision: more than 300 degrees. Each eye covers different areas, focusing on the same object only when looking ahead through a narrow binocular field of vision.



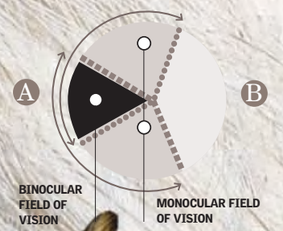
THE HUMAN FIELD OF VISION

The eyes, located at the front, move together, covering the same area. Because human beings cannot move their eyes independently from each other, they have only binocular vision.



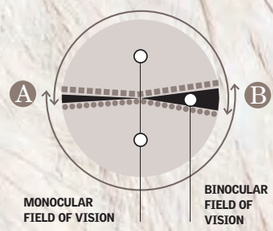
COMPARISON OF BINOCULAR FIELDS OF VISION

Binocular vision is essential for measuring distances without making mistakes. The brain processes the images that each eye generates separately as if they were a single image. The small differences between the two images allow the brain to create a third one in depth, or in three dimensions. Hunting birds, for which the correct perception of distance is a life-and-death matter, tend to have eyes located toward the front, with a wide field of binocular vision. In contrast, birds with lateral eyes calculate distance by moving their heads, but they record a larger total field of vision to avoid becoming prey. Owls are the birds with the greatest binocular vision—up to 70 degrees.



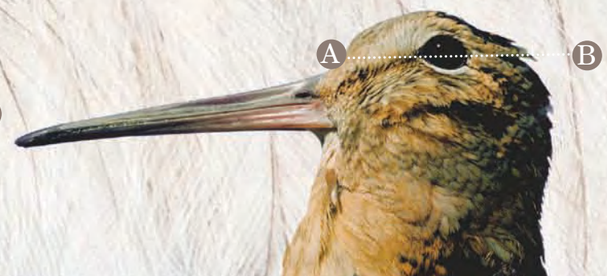
HUNTING BIRDS' FIELD OF VISION

Frontal eyes reduce the total field of vision but allow for a wide field of binocular vision.



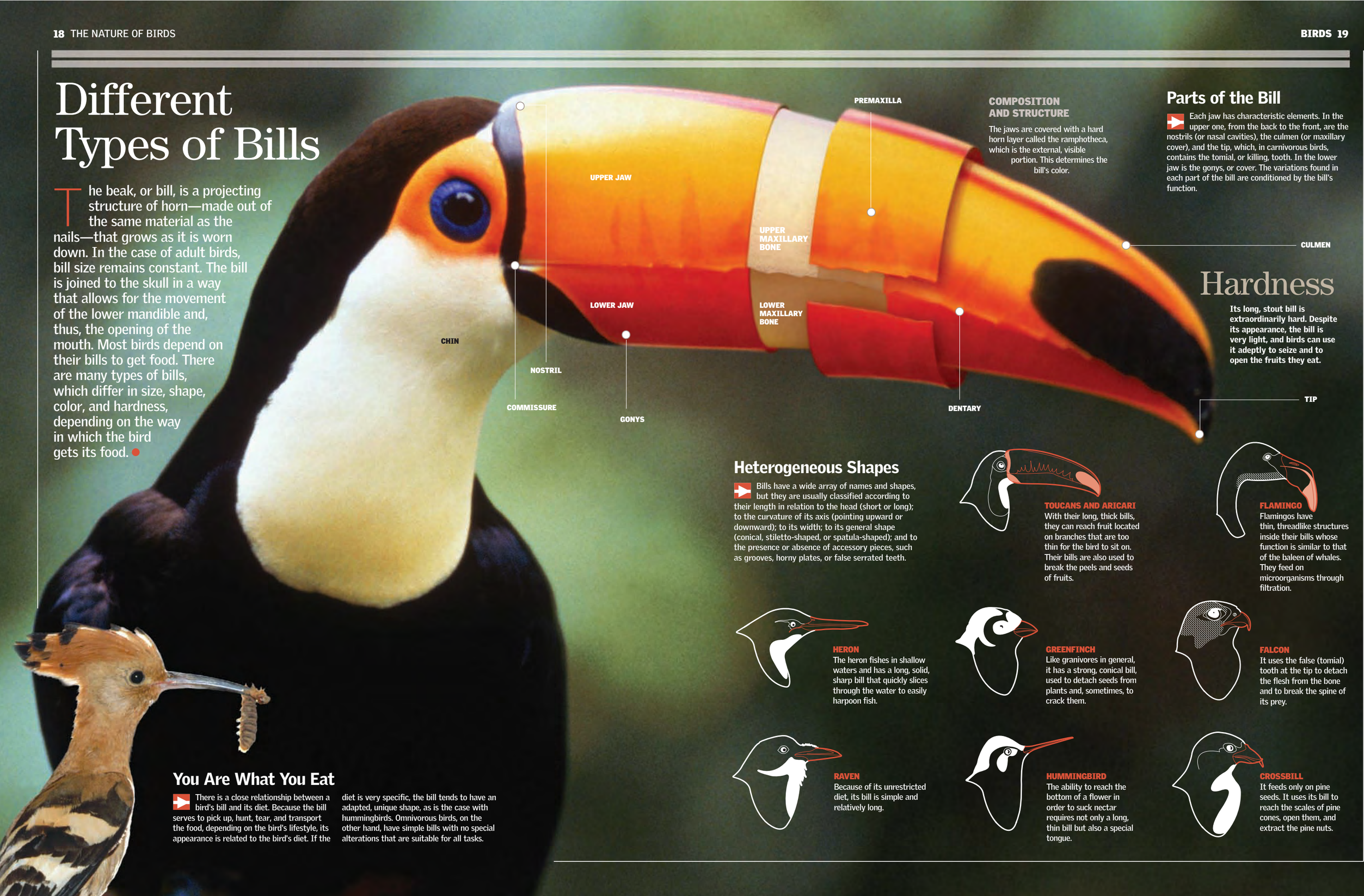
NONHUNTING BIRDS' FIELD OF VISION

The lateral eyes open the field of vision to as much as 360 degrees but reduce the binocular field.



Different Types of Bills

The beak, or bill, is a projecting structure of horn—made out of the same material as the nails—that grows as it is worn down. In the case of adult birds, bill size remains constant. The bill is joined to the skull in a way that allows for the movement of the lower mandible and, thus, the opening of the mouth. Most birds depend on their bills to get food. There are many types of bills, which differ in size, shape, color, and hardness, depending on the way in which the bird gets its food.



COMPOSITION AND STRUCTURE

The jaws are covered with a hard horn layer called the ramphotheca, which is the external, visible portion. This determines the bill's color.

Parts of the Bill

Each jaw has characteristic elements. In the upper one, from the back to the front, are the nostrils (or nasal cavities), the culmen (or maxillary cover), and the tip, which, in carnivorous birds, contains the tomial, or killing, tooth. In the lower jaw is the gonys, or cover. The variations found in each part of the bill are conditioned by the bill's function.

Hardness

Its long, stout bill is extraordinarily hard. Despite its appearance, the bill is very light, and birds can use it adeptly to seize and to open the fruits they eat.

You Are What You Eat

There is a close relationship between a bird's bill and its diet. Because the bill serves to pick up, hunt, tear, and transport the food, depending on the bird's lifestyle, its appearance is related to the bird's diet. If the diet is very specific, the bill tends to have an adapted, unique shape, as is the case with hummingbirds. Omnivorous birds, on the other hand, have simple bills with no special alterations that are suitable for all tasks.

Heterogeneous Shapes

Bills have a wide array of names and shapes, but they are usually classified according to their length in relation to the head (short or long); to the curvature of its axis (pointing upward or downward); to its width; to its general shape (conical, stiletto-shaped, or spatula-shaped); and to the presence or absence of accessory pieces, such as grooves, horny plates, or false serrated teeth.

TOUCANS AND ARICARI
With their long, thick bills, they can reach fruit located on branches that are too thin for the bird to sit on. Their bills are also used to break the peels and seeds of fruits.

FLAMINGO
Flamingos have thin, threadlike structures inside their bills whose function is similar to that of the baleen of whales. They feed on microorganisms through filtration.

HERON
The heron fishes in shallow waters and has a long, solid, sharp bill that quickly slices through the water to easily harpoon fish.

GREENFINCH
Like granivores in general, it has a strong, conical bill, used to detach seeds from plants and, sometimes, to crack them.

FALCON
It uses the false (tomial) tooth at the tip to detach the flesh from the bone and to break the spine of its prey.

RAVEN
Because of its unrestricted diet, its bill is simple and relatively long.

HUMMINGBIRD
The ability to reach the bottom of a flower in order to suck nectar requires not only a long, thin bill but also a special tongue.

CROSSBILL
It feeds only on pine seeds. It uses its bill to reach the scales of pine cones, open them, and extract the pine nuts.

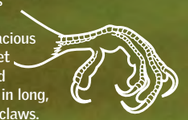
Exposed Legs

Taking a quick look at the extremities of birds, including their toes and claws, can help us learn about their behavior. The skin of their legs and feet can have some striking features. All these characteristics reveal information about the environments in which different groups of birds live, as well as about their diets. Scientists use these characteristics as a basis for classifying birds. The detailed study of the anatomy of a bird's leg and foot can offer useful information. The shape and placement of bones, muscles, and tendons make it possible to understand how birds hold their prey or perch on branches, as well as to learn about the mechanics of their movement across the ground and in the water.

Different Types

The foot usually has four toes. Three of them have a similar size and position. Opposite them is a smaller toe called the hallux. This pattern varies among different bird groups. For example, the position and shape of toes can differ. There are even cases in which two toes are functional while the others have been reduced in size. This is the case with flightless birds such as rheas. Differences are also found in the skin, which may form a web between the toes and projections of horn. All these characteristics become tools to help the bird survive in its environment and face challenges regarding obtaining food.

FEET DESIGNED FOR SEIZING
Found on birds of prey and nocturnal rapacious birds. Their feet are strong, and their toes end in long, curved, sharp claws. They seize prey and transport it in flight.

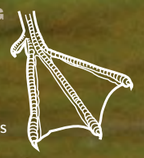


FEET DESIGNED FOR CLIMBING
Found on parrots, woodpeckers, and cuckoos. The hallux and the fourth toe are pointed backward. This arrangement provides the birds with more strength for climbing tree trunks.

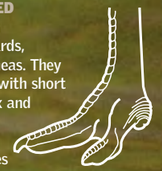
FEET DESIGNED FOR WALKING
Found on herons, flamingos, and storks. The toes and legs are very long. The hallux is pointed backward. They live in places with soft ground, such as swamps and river banks.

FEET DESIGNED FOR PERCHING
Found on hummingbirds, kingfishers, ovenbirds, and nightjars. They have small feet, with the second, third, and fourth toes joined together. This makes it possible for them to stand still.

FEET DESIGNED FOR SWIMMING
Alcas, patos y
Found on auks, ducks, and penguins, which have a membrane between their toes that forms a web and increases the surface of the foot that is in contact with the water.

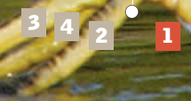


FEET DESIGNED FOR RUNNING
Found on bustards, curlews, and rheas. They have long legs with short toes. The hallux and the fourth toe are very small, which decreases contact with the ground while running.



Adaptation to Trees
The common waxbill perches and sleeps on tree branches without expending much energy. The weight of the body alone causes its toes to close tightly around the branch.

THE FOOT I
Toes 1 (hallux) and 2 have three phalanges, toe 3 has four, and toe 4 has five.



TRICOLORED HERON
Its feet have long, thin toes that allow it to move on soft ground, such as in swamps, on river banks, and on lake shores. It lives in the regions of Arica and Coquimbo in Chile.

THE FOOT II
The distal tarsal bones merge into the metatarsal bone and create tarsometatarsal bones.

KNEE AND THIGH
The thigh is included in the body and has a shortened femur. The knee is near the center of gravity.

TIBIA
The tibia merges into tarsal bones and forms the tibiotarsus. It has a slightly developed fibula on its lateral face.

ANKLE
Also known as a false knee because it looks like a knee that flexes backward. In reality, it is the ankle.

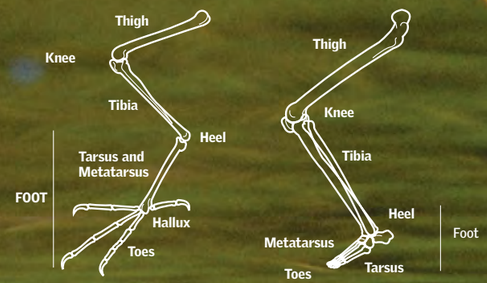
Claws, Scales, and Spurs

These striking foot structures play a role in finding food, movement, protection, and defense, among other things. The claws can be long and sharp, in the case of birds of prey, or short and round, in the case of walking birds. Owls have a comblike claw that they use to groom their plumage. Their scales, inherited from reptiles, help protect their feet. In some cases, they help the birds to move through water. Many birds, such as chickens, pheasants, and crested screamers (a South American waterbird), have a spur, which they use as a defensive or offensive weapon.

BALD EAGLE (Talons)
Very long, curved, pointed claws. They envelop the body of the prey and pierce it.

GREAT CRESTED GREBE (Lobed Toes)
In some swimming birds, the toes look like oars. They have a continuous wide border.

SCOTS DUMPY ROOSTER (Spurs)
The spurs originate in skin and bone tissues. When males fight over territory or over a female, they use their spurs to defend themselves.



Internal/External Structure

Birds walk on their toes, which form the first portion of their feet. The second portion is formed by the tarsometatarsus. Its top part is connected to the tibia, through a joint similar to that of our ankle. That is why the leg flexes backward. The knee, equivalent to ours, is higher up and works like a hip. It is located close to the body, and it helps to maintain balance. The thigh bone also stabilizes the body by adding weight to the skeleton. All the movements of these bones are controlled by tendons and muscles.

The Art of Flying

PARROT FEATHER
Detail of the feathers worn by these colorful aerial acrobats

ADAPTATIONS 24-25
FEATHERS 26-27
WINGS TO FLY 28-29
TAIL TYPES 30-31
TO RENEW IS TO LIVE 32-33
GLIDING 34-35
FLAPPING FLIGHT 36-37
SPEED RECORDS 38-39

Birds move in the air the same way a glider does, that is, by making the most of air currents to gain height and speed while moving. The shape of the wings varies according to the needs of each bird group. Some cover considerable distances and thus have long, narrow wings, whereas others have short, rounded wings that allow them to make short flights from branch to branch. Birds also have shiny, colorful feathers that males frequently use both to attract females and to hide from enemies.

Feathers are usually renewed once a year, and this process is as vital to birds as feeding. ●

Adaptations

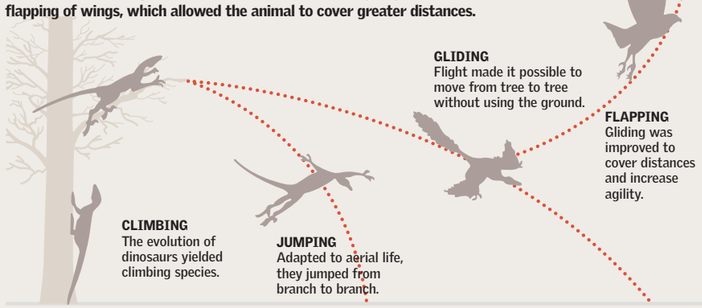
There are three main theories to explain why birds developed the ability to fly. The evidence that supports each of them tells a story of adaptations to an aerial world in which the fight for food and survival is key. One reasonable theory argues that birds descended from an extinct line of biped reptiles that fed on plants and used to jump from branch to branch to flee.

From Reptile to Bird

It is known that several evolutionary lineages from both reptiles and birds did not survive the evolutionary process, and that the lineage that truly links these two animal groups has not yet been found. However, some theories state that the change from reptile to bird took place through a long process of adaptation. There are two arguments and a variant: the arboreal theory, which posits an air-ground flight model; the cursory (or running) theory, which focuses on the need for stability when running; and a variant, related to parental care, which posits that dinosaurs started to fly as a way of keeping their eggs safe.

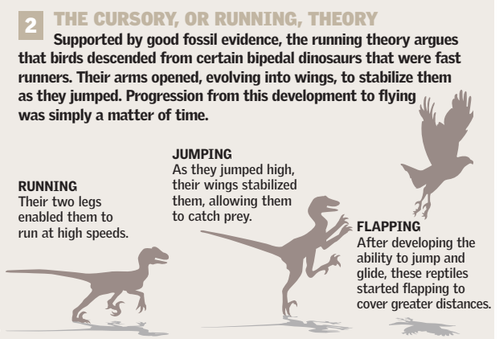
1 THE ARBOREAL THEORY

This theory, the most accepted for a long time, states that flight was an adaptation to the environment in which certain herbivorous climbing reptiles lived. At first, dinosaurs developed a kind of parachute to protect them if they missed a branch when jumping, and later it became a way to move from tree to tree. Finally, flight evolved to involve the flapping of wings, which allowed the animal to cover greater distances.



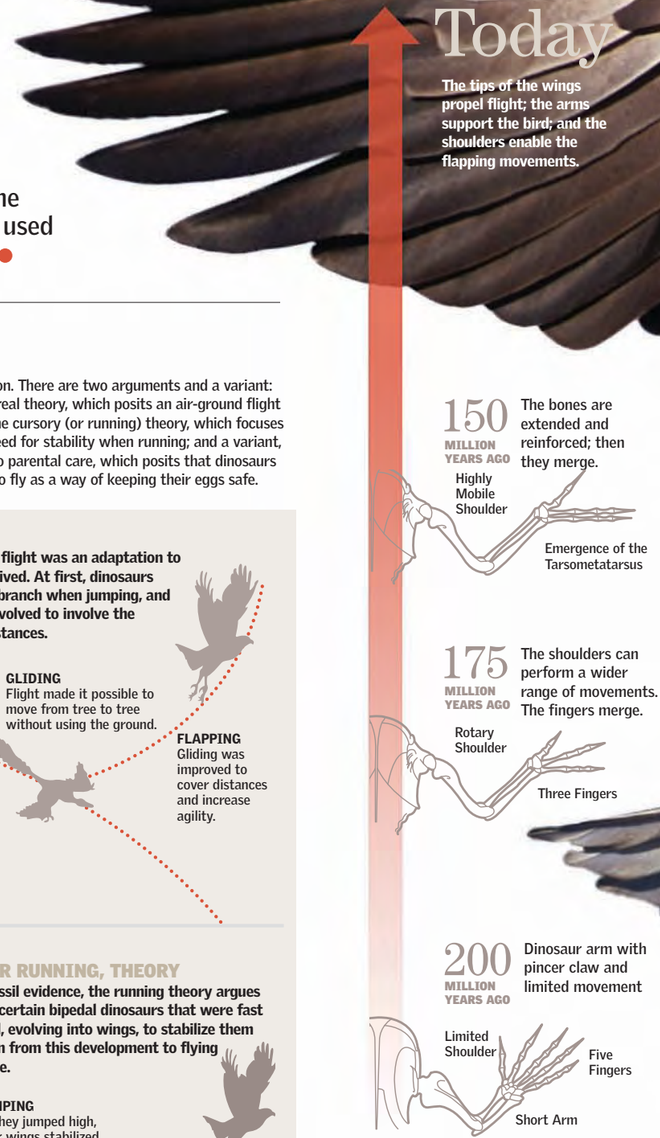
2 THE CURSORY, OR RUNNING, THEORY

Supported by good fossil evidence, the running theory argues that birds descended from certain bipedal dinosaurs that were fast runners. Their arms opened, evolving into wings, to stabilize them as they jumped. Progression from this development to flying was simply a matter of time.



3 PARENTAL CARE VARIANT

This variant proposes that reptiles started to climb trees to prevent their young from becoming prey. Gliding removed the need to climb out of the trees.



THE EMERGENCE OF THE WING

It evolved from an arm with a talon into a limb, without a talon, that was adapted for flight. The causes of this change are not yet clear to scientists. However, fossil records show how bones merged until they reached their present forms.

OTHER FLYING ANIMALS

In flying animals, from primitive pterodactyls to bats, wings have always been a flap of skin. A tear creates serious problems because it takes time to heal, and the wing may be misshapen afterward.

THE BEST SOLUTION

Feathers are a unique evolutionary advantage. Their versatility, strength, individual nature, and ease of replacement make them an ideal adaptation to flight for vertebrates.

EAGLE

In its maneuvers, this great hunter displays the entire evolution of flight.

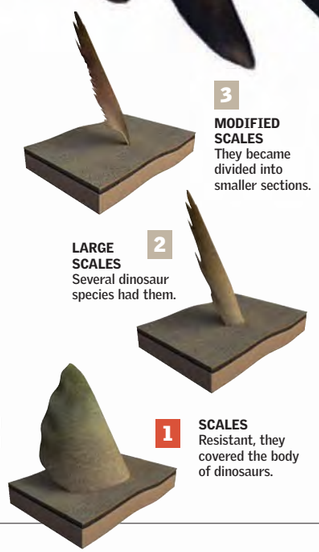
4 FEATHERS

Today found only on birds, feathers are scales partitioned into three smaller sections. They form a light, uniform, resistant network that covers the whole body.

26 pounds (12 kg)

IS THE MAXIMUM WEIGHT AN EAGLE CAN CARRY DURING FLIGHT.

The eagle itself usually weighs about 13 pounds (6 kg) and can generally carry prey weighing 6.5 pounds (3 kg). Some eagles, however, have been seen carrying prey estimated to weigh 13 pounds (6 kg). Carrying any more weight would require bigger wings, which would be more difficult to move and less efficient. It is believed that large flying animals disappeared because of this limitation.



FROM SCALES TO FEATHERS

The development of feathers brought great advantages to birds because feathers enabled them to fly. Feathers evolved from scales, and they are made of the same material. Feathers keep the body's temperature constant and are lighter than scales.

Feathers

Feathers are the feature that distinguishes birds from all other animals. They make birds strikingly colorful, protect them against cold and intense heat, enable them to move easily through the air and water, and hide them from enemies. Feathers are also one of the reasons why human beings have domesticated, caught, and hunted birds. A bird's set of feathers is called its plumage, and its color is essential for reproductive success.

Structure

The structure of feathers has two parts: a shaft and a blade. The shaft is called the rachis, and the part connected to the bird's skin is called the calamus. The movement of a feather is generated in the rachis. The blade is composed of barbs that branch into barbules. The feather's blade, in which the barbules have a series of barbicels, or hooklets, at the tip, is called a vane. The interlocking hooklets in the vane create a network that adds rigidity and resistance to the feather. It also defines the characteristic aerodynamic shape of feathers and helps make the feather waterproof. When feathers wear out, birds have the ability to replace them with new ones.

1 A swelling, or papilla, develops in the bird's skin.

2 In the papilla, special skin cells form a follicle.

3 A tube that will extend from its base and become a feather grows in the follicle.

HOLLOW INTERIOR

INFERIOR UMBILICUS
The orifice at the base of the calamus, into which the dermic papilla penetrates. New feathers receive nourishment through it.

INNER PULP OF THE SHAFT

CALAMUS
It provides the necessary nutrients for feathers to grow. Nerve endings that stimulate the feather's movement are found at its base. This allows the bird to detect changes in its surroundings.

SUPERIOR UMBILICUS
It contains some loose barbs. Some feathers have a secondary rachis, the hyporachis.

BARBS
are slim, straight ramifications that grow perpendicular to the rachis.

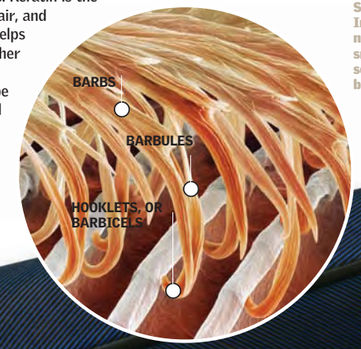
RACHIS
A feather's main shaft, similar to a hollow rod

EDGE
The edge presents an excellent aerodynamic profile for flying.

VANE, OR BLADE
Its outer portion contains a great number of barbicels.

WHAT IS KERATIN?

Keratin is a protein that forms part of the outermost layer of a bird's skin, just as it does in other vertebrate animal groups. Keratin is the main component of feathers, hair, and scales. Its distinct resistance helps keep the hooklets woven together in the vane. This allows birds' feathers to maintain their shape in spite of the pressure exerted by the air during flight.



25,000

THE NUMBER OF FEATHERS THAT LARGE BIRDS, SUCH AS SWANS, CAN HAVE. In contrast, the number of feathers small birds, such as songbirds, can have varies between 2,000 and 4,000.

TRAILING EDGE NOTCH
The turbulence during flight is reduced by this notch, found near the tip of the wing.

PREENING THE PLUMAGE

Birds need to preen their feathers with their bills not only to keep them clean and free of parasites but also to keep them lubricated, which helps birds resist inclement weather. Birds touch their uropygial, or preen, glands with their bills. Then they distribute the oil and wax this gland produces all over their plumage. This task is a matter of survival.

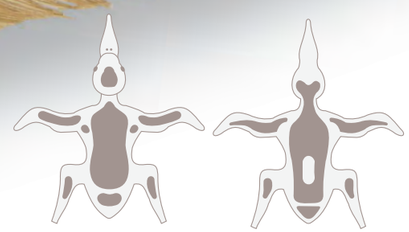
SELF-CLEANING WITH ANTS

Some birds, such as certain tanagers, catch ants with their bills and grind them. They then oil their feathers with the ground-up ants. It is believed that the acid juices from the squashed ants work as a repellent against lice and other external parasites.

DUST BATH

Birds such as pheasants, partridges, ostriches, pigeons, and sparrows perform dust baths to control the amount of grease on their feathers.

IMPERIAL HERON
Powder down keeps its plumage waterproof.



PTERYLAE AND APTERIA

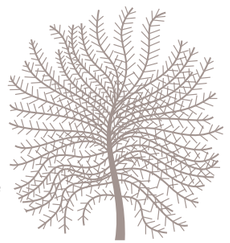
At first glance, a bird's body is covered with feathers. However, feathers do not grow all over the body but rather in particular areas called pterylae. This is where the papillae, which create new feathers, are found. The shape and placement of pterylae vary according to species. Pterylae are surrounded by naked areas, called apteria, in which feathers do not grow. Penguins are the only birds whose bodies are completely covered with feathers. This characteristic makes it possible for them to live in cold regions.

Types of Feathers

There are three main types of feathers, classified according to placement: those closest to the body are down, or underlying feathers; those at the top are contour feathers; and those on the wings and tail are flight feathers, which are often referred to as remiges (on the wings) and rectrices (on the tail).

DOWN

These light and silky feathers protect the bird against the cold. They have a short rachis, or none at all. Their barbs are long, and their barbules lack hooklets. In general, down is the first type of feather that birds develop when they hatch.

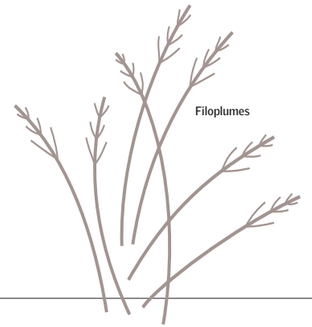


CONTOUR

Also called covert feathers, they are short and rounded. They are more rigid than down feathers. Because they cover the body, wings, and tail, they give birds their shape as they fly.

SPECIAL FEATHERS

Vibrissae are special feathers formed by only one filament. Sometimes they have loose barbs at the base that perform a tactile function. They are located at the base of bills or nostrils or around the eyes. They are very thin and are usually blended with contour feathers.



POWDER DOWN

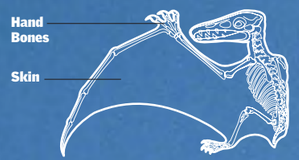
This special type of feather can be found on some aquatic birds. They grow constantly and break off at the tip into small waxy scales. This "powder" is preened into the plumage to provide protection.

Wings to Fly

Wings are highly modified arms that, through their unique structure and shape, enable most birds to fly. There are many types of wings; they vary by species. For instance, penguins, which are flightless, use their wings for the specialized task of swimming. Among all wings that have existed in the animal kingdom, those of birds are the best for flying. Their wings are light and durable, and in some cases their shape and effectiveness can be modified during flight. To understand the relationship between wings and a bird's weight, the concept of wing loading, which helps explain the type of flight for each species, is useful.

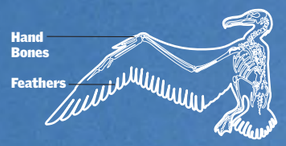
Wings in the Animal Kingdom

Wings have always been modified arms, from the first models on pterosaurs to those on modern birds. Wings have evolved, beginning with the adaptation of bones. Non-avian wings have a membranous surface composed of flexible skin. They extend from the bones of the hand and body usually down to the legs, depending on the species. Avian wings, on the other hand, are based on a very different principle: the arm and hand form a complex of skin, bone, and muscle, with a wing surface consisting of feathers. Furthermore, the avian wing allows for important changes in form, depending on the bird's adaptation to the environment.



PTERODACTYLS
still had talons, and only one finger extended their wings.

BATS
Four fingers extend the membrane, and the thumb remained as a talon.

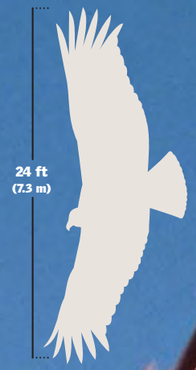


BIRDS
The fused fingers form the tip of the wing where the rectrices, or primary feathers, are attached.

WANDERING ALBATROSS

Wing Size and Loading

The wingspan is the distance between the tips of the wings. Together with width, it determines the surface area, which is an essential measurement for bird flight. Not just any wing can support any bird. There is a close relationship between the animal's size (measured by weight) and the surface area of its wings. This relationship is called wing loading, and it is crucial in understanding the flight of certain species. Albatrosses, with large wings, have low wing loading, which makes them great gliders, whereas hummingbirds have to flap their small wings intensely to support their own weight. The smaller the wing loading, the more a bird can glide; the bigger, the faster a bird can fly.



ARGENTAVIS MAGNIFICENS **(extinct)**

PRIMARIES
They are in charge of propulsion; they are also called remiges.

PRIMARY COVERTS
They cover the remiges and, with the alula, change the wing shape at will.

LARGER FINGER

SMALLER FINGER

CARPOMETACARPUS

ALULAR DIGIT
Controls the alula, a feathered projection on the front edge of the wing.

ULNA

RADIUS

MEDIAN WING COVERTS
They change the wing's lift when they rise slightly.

SECONDARIES
Their number varies greatly depending on the species. They complete the surface.

HUMERUS

GREATER WING COVERTS
They create more surface area and cover the intersection point of the tertiaries.

CORACOID

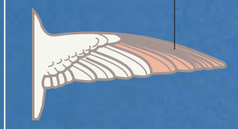
TERTIARIES
Together with the secondaries, they create the wing's surface.

STERNUM OR KEEL

Types of Wings

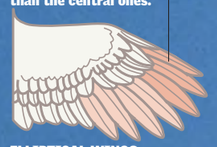
According to the environment in which they live and the type of flight they perform, birds have different wing shapes that allow them to save energy and to perform efficiently during flight. The wing shape also depends on the bird's size. Consequently, the number of primary and secondary feathers changes depending on the needs of a given species.

The external primary feathers are longer.



FAST WING
Remiges are large and tight to allow for flapping; the surface is reduced to prevent excessive friction.

The outermost primary feathers are shorter than the central ones.

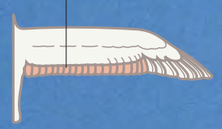


ELLIPTICAL WINGS
Functional for mixed flights, they are very maneuverable. Many birds have them.

They are wide at the base, with separate feather tips.

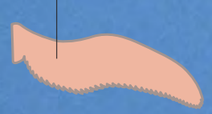
WINGS FOR SOARING ABOVE LAND
Wide, they are used to fly at low speeds. The separate remiges prevent turbulence when gliding.

There are many secondary feathers.



WINGS FOR SOARING ABOVE THE OCEAN
Their great length and small width make them ideal for gliding against the wind, as flying requires.

Short feathers are located all over the wing.



WINGS FOR SWIMMING
In adapting to swimming, the feathers of penguins became short, and they serve primarily as insulation.

Flightless Wings

Among these, penguins' wings are an extreme case of adaptation: designed for rowing underwater, they work as fins. On running birds, wings' first and foremost function is to provide balance as the bird runs. These wings are also related to courtship, as birds show off their ornamental feathers during mating season by opening their wings or flapping them. Wings are also very efficient at controlling temperature, as birds use them as fans to ventilate their bodies.

FUNCTION
The wings of ostriches carry out the functions of balancing, temperature regulation, and courtship.

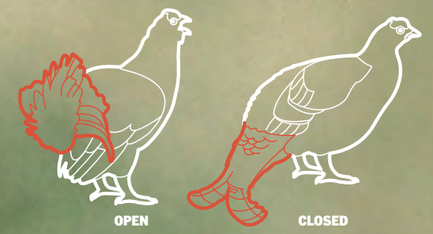
LOOSE FEATHERS
Sometimes barbicels are missing, and feathers on the wing come apart, creating a loose and ruffled appearance.

PRIMARY FEATHERS
Flying birds have from nine to 12 primary feathers. Running birds may have up to 16.

Over the course of evolution, birds' tail vertebrae fused into a pygostyle, and in their place feathers of different sizes and colors emerged. These feathers have multiple uses: they can control aerial maneuvers during flight, work as brakes during landing, and make noise. Males also use them during courtship to dazzle and win over females. Usually the tail is formed by rectrices that vary in number, length, and rigidity depending on the species.

Courtship Display

The tail feathers of the female black grouse are straight, whereas those of the male have a half-moon shape. They usually keep the feathers closed and near the ground, but during the courtship displays they spread them out and show them off completely. To finish the show, the male runs back and forth in front of the female.



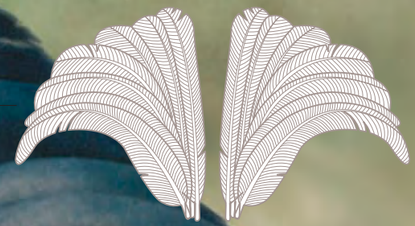
The Key to How It Works

The tail can perform a variety of functions because of the movement and shape of the feathers. The powerful muscles in the pygostyle prepare the plumage for courtship displays and for flight, provide balance in walking and alighting on trees, and work as rudders for swimming.

LANDING I
The plumage spreads out, and the main axis of the body is positioned parallel to the ground.

LANDING II
The body leans backward, and the tail closes. The legs prepare to grab the branch.

LANDING III
The spread-out tail feathers, together with an intense flapping of the wings, make it possible for the bird to slow down and prepare its body to land.



RECTRICES
Tail feathers can wear out and fray because of friction during flight or by brushing against vegetation.

UNDERTAIL COVERTS
Feathers that cover the lower part of rectrices, protecting them against the wear and tear caused by air friction

Black Grouse
Lyrurus tetrix

The male is recognized by its bluish black plumage and the red caruncle over its eyes.

Fan of Rectrices

On flying birds, it is light and aerodynamic. On tree-climbing birds, such as woodpeckers, the plumage is rigid, which allows them to use it as a support (pointed tail). The coverts of male peacocks are more developed than their rectrices so that the peacock can show them off.

FORKED TAIL
Found on swallows and frigate birds. The external feathers are very long and look like scissors.

ROUNDED TAIL
Found on some songbirds. The central feathers are only slightly longer than the external ones.

GRADUATED TAIL
Found on trogons and kingfishers. When closed, the tail has a layered shape.

MARGINATED TAIL
Found on blue jays. The central feathers are only slightly shorter than the external ones.

SQUARE TAIL
Found on quails. The tail is short, with even-sized feathers.

To Renew Is to Live

The periodic renewal of plumage is called molting. It is the replacement of worn-out, older feathers with new ones that are in better condition. In a bird's life cycle, molting is as important an event as migrating or caring for young. The beginning of this phenomenon is determined by environmental factors that trigger a series of hormonal stimuli in birds: they start to eat more and to decrease their other activities. This, in turn, causes them to gain weight through an accumulation of fat that will serve as the source of energy for developing new plumage.

Plumage Molting

The main function of molting is to replace worn-out plumage. It also helps the bird adapt its appearance to the seasons and to different stages in life. The renewal can be partial or total. Some feathers are replaced before the spring, when the task is to attract a partner for reproductive purposes. In the fall, before birds have to start caring for their young, the renewal is complete. On most birds, molting takes place in each pteryla, following a determined order. Penguins, however, renew all their feathers at the same time, within two to six weeks.

SEASONAL CHANGE

In the high mountains, snow transforms the landscape during winter. During this time, nonmigratory birds exchange their summer plumage for a winter one. This change helps them to protect themselves from predators.

PTARMIGAN

SUMMER PLUMAGE
The feathers have deep pigmentation. This helps birds blend in with the vegetation.

WINTER PLUMAGE
The new, unpigmented feathers make it possible for ptarmigans to blend with the white snow.

Order of Replacement

Many species start molting, a process triggered by hormones, in a specific order. Molting starts with remiges and wing coverts, continues with rectrices, and finishes with body coverts. This gradual process keeps the body temperature stable.

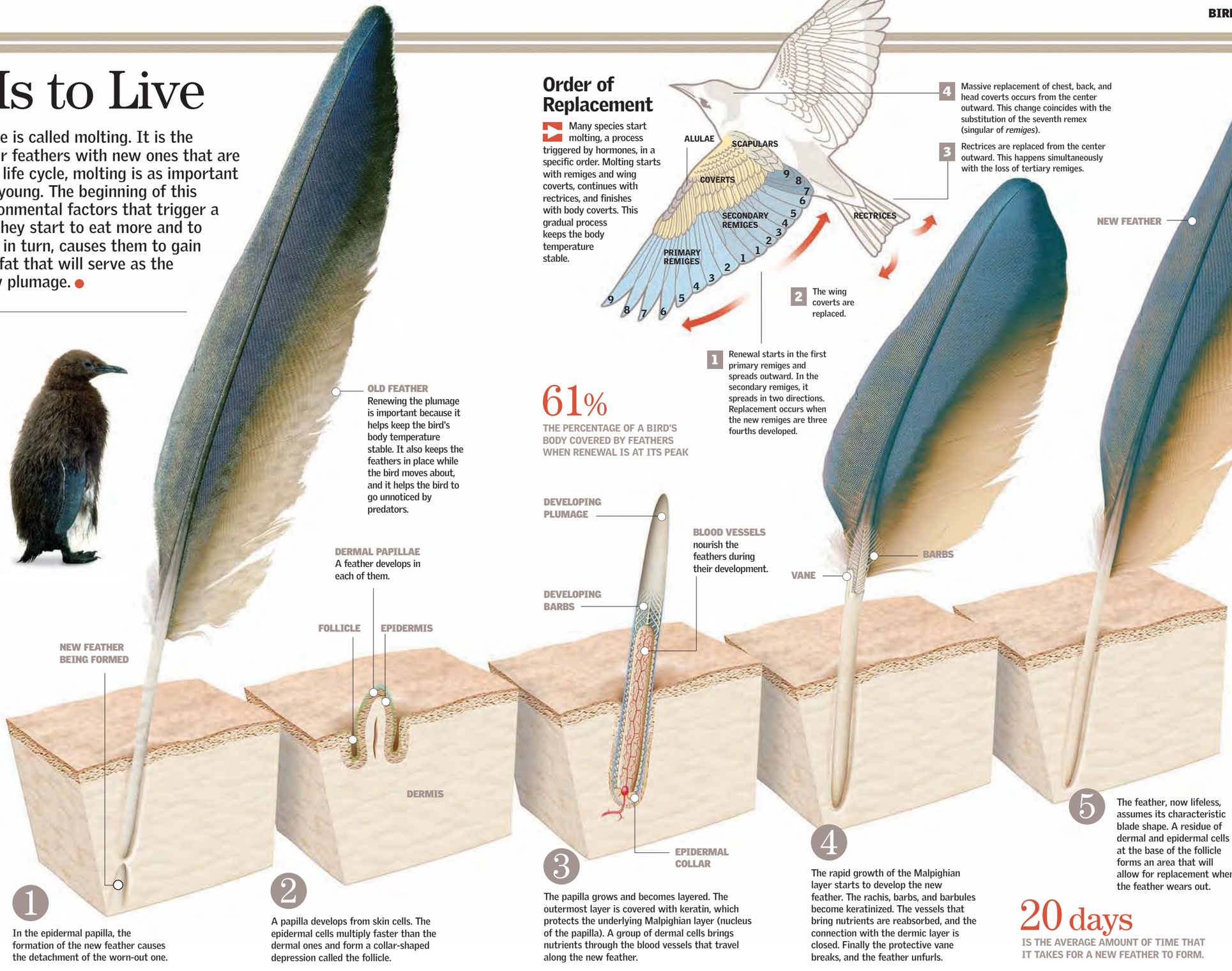
4 Massive replacement of chest, back, and head coverts occurs from the center outward. This change coincides with the substitution of the seventh remex (singular of *remiges*).

3 Rectrices are replaced from the center outward. This happens simultaneously with the loss of tertiary remiges.

2 The wing coverts are replaced.

1 Renewal starts in the first primary remiges and spreads outward. In the secondary remiges, it spreads in two directions. Replacement occurs when the new remiges are three fourths developed.

61%
THE PERCENTAGE OF A BIRD'S BODY COVERED BY FEATHERS WHEN RENEWAL IS AT ITS PEAK



1 In the epidermal papilla, the formation of the new feather causes the detachment of the worn-out one.

2 A papilla develops from skin cells. The epidermal cells multiply faster than the dermal ones and form a collar-shaped depression called the follicle.

3 The papilla grows and becomes layered. The outermost layer is covered with keratin, which protects the underlying Malpighian layer (nucleus of the papilla). A group of dermal cells brings nutrients through the blood vessels that travel along the new feather.

4 The rapid growth of the Malpighian layer starts to develop the new feather. The rachis, barbs, and barbules become keratinized. The vessels that bring nutrients are reabsorbed, and the connection with the dermic layer is closed. Finally the protective vane breaks, and the feather unfurls.

5 The feather, now lifeless, assumes its characteristic blade shape. A residue of dermal and epidermal cells at the base of the follicle forms an area that will allow for replacement when the feather wears out.

20 days
IS THE AVERAGE AMOUNT OF TIME THAT IT TAKES FOR A NEW FEATHER TO FORM.

Gliding

Involves using air currents to fly and save energy when traveling long distances. There are two types of gliders, terrestrial birds and marine birds, each of which is adapted to different atmospheric phenomena. Terrestrial birds rise on thermals (rising air currents). Marine birds make use of oceanic surface winds. Once the birds gain altitude, they glide off in straight paths. They slowly lose altitude until encountering another thermal that will lift them. Both terrestrial and marine gliders have wings of considerable size.

TYPES OF GLIDING FEATHERS

Terrestrial Glider
A large wing surface allows it to make the most of rising air currents at moderate speed.

Marine Glider
Thin and long wings allow it to make the most of the constant surface winds and offer less resistance to forward movement.

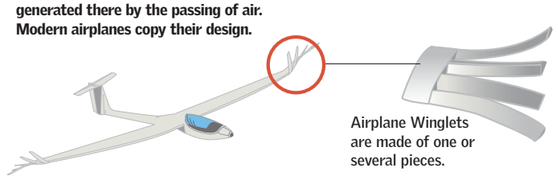
Takeoff

Usually, a powerful jump followed by the vertical flapping of the wings is enough to make a bird take flight. As it descends, the tip feathers are stacked on top of each other, forming an airtight surface that helps drive the bird upward. As the bird raises its wings to repeat the movement, the feathers curve and open until the wing reaches its highest point. With a couple of flaps of the wings, the bird is in flight. Bigger birds need a running start on the ground or water in order to take off.

70%
THE ENERGY SAVED BY A SEAGULL WHILE GLIDING

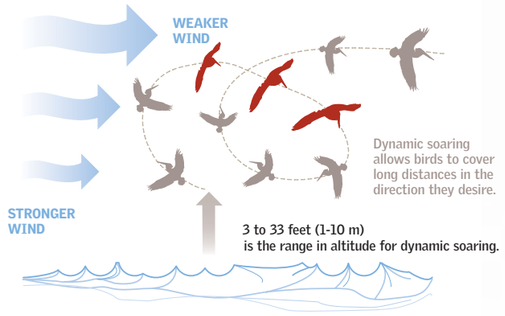
WINGLETS

Terrestrial gliders usually have separate primary feathers (toward the tip of the wing) that serve to decrease the noise and tension generated there by the passing of air. Modern airplanes copy their design.



Marine Birds

Dynamic soaring is performed by birds with long and thin wings, such as the albatross. These wings are designed to take advantage of horizontal air currents, which are responsible for the formation of waves in the ocean. The result is a flight consisting of a series of loops as the bird is lifted upward when it faces the wind and moved forward when it faces away from the wind. This kind of flight can be performed at any time.



FLIGHT PATTERNS

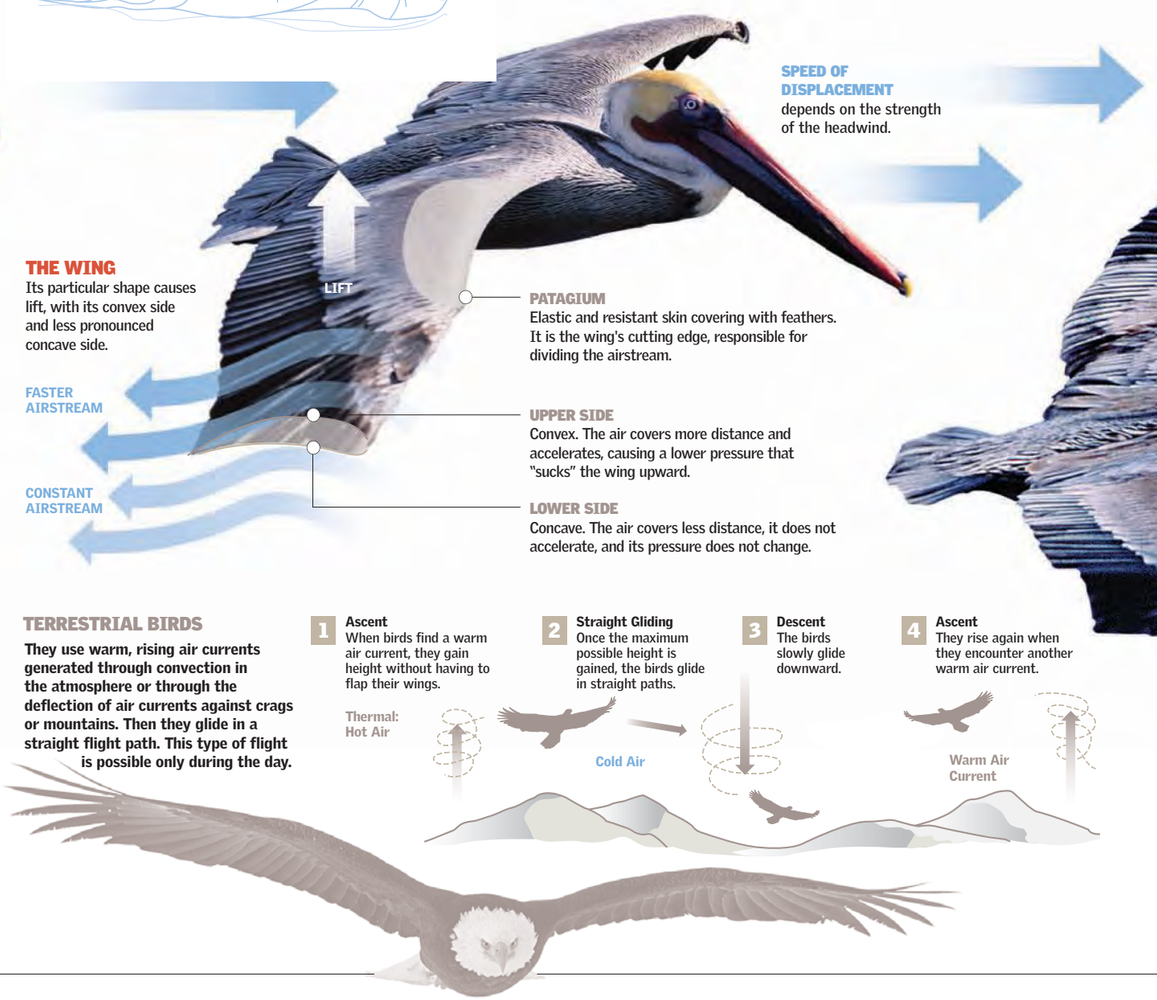
Flying in formation is a way for birds in flapping flight to save energy. The leader encounters more resistance as it flies, while the others take advantage of its wake. There are two basic patterns: "L" and "V." The first is used by pelicans, and the second is used by geese.

"L" FORMATION
Leader
The leader makes the most effort, as it "parts" the air.

The Rest of the Formation
The other birds make use of the turbulence produced by the leader's flapping to gain height, following along behind.

14%
THE PERCENTAGE OF WING FLAPPING THAT GEESE SPARE THEMSELVES BY FLYING IN FORMATION

"V" FORMATION
The principle is the same, but the birds form two lines that converge at a point. This is the usual formation used by geese, ducks, and herons.



TERRESTRIAL BIRDS

They use warm, rising air currents generated through convection in the atmosphere or through the deflection of air currents against crags or mountains. Then they glide in a straight flight path. This type of flight is possible only during the day.

1 Ascent
When birds find a warm air current, they gain height without having to flap their wings.

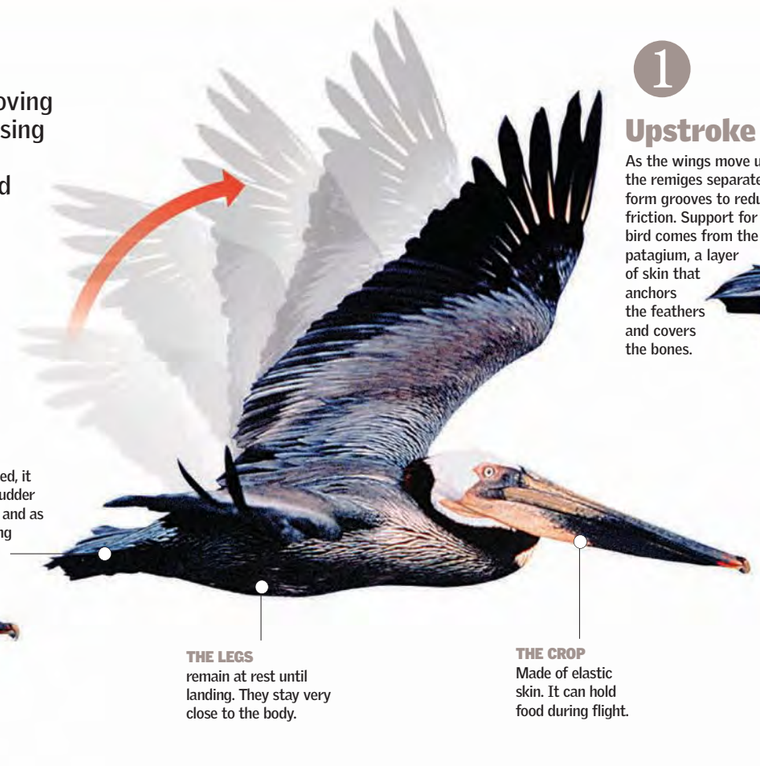
2 Straight Gliding
Once the maximum possible height is gained, the birds glide in straight paths.

3 Descent
The birds slowly glide downward.

4 Ascent
They rise again when they encounter another warm air current.

Flapping Flight

Most flying birds use flapping flight all the time. It consists of moving through the air as if rowing with the wings. With each flap (raising and lowering), the wing both sustains the bird in the air and pushes its body forward. There are different types of flapping flight and different rates of flapping. In general, the larger the bird, the more powerful and less frequent its flapping will be. Because flapping is an activity that consumes much energy, birds have adapted a variety of flight patterns: some, like hummingbirds, always flap their wings, whereas others alternate flapping with short-term gliding. The wing shape also varies according to the bird's needs. Birds that cover long distances have long, narrow wings; those that fly among trees have short, rounded wings.



30 miles per hour (50 km/h)

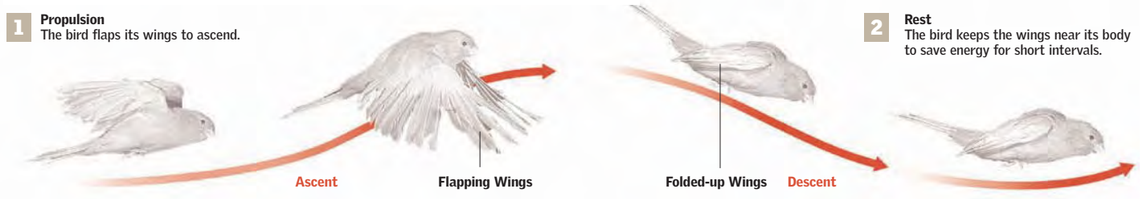
THE AVERAGE SPEED OF AN ADULT PELICAN DURING FLIGHT ON A WINDLESS DAY

A Specialized Design

Flapping flight is an activity that requires much effort. Therefore, birds must eat large amounts of food. A migrating swallow uses 4 kilocalories (4,000 calories) per 1.6 miles (2.5 km) of flight, whereas a small mammal needs only about 0.025 kilocalorie (25 calories) to travel the same distance.

WAVELIKE FLIGHT PATH

Ideal for high speeds, it consists of flapping the wings to gain height and then folding them in order to descend along the flight's trajectory. Afterward the bird flaps its wings again, making use of the inertia of its descent to regain height. A variation of this type of flight involves gliding between flaps of the wings.



WINDMILL FLIGHT: HUMMINGBIRDS

Hummingbirds are able to hover in order to suck the nectar out of flowers. In contrast to other birds, hummingbirds' wings are attached only at the shoulders, which provides greater freedom of wing movement, allowing the hummingbird to hold itself in the air during both the upstroke and the downstroke. The hummingbird has to flap its wings up to 4,800 times per minute during directional flight and for hovering.

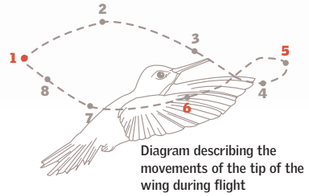


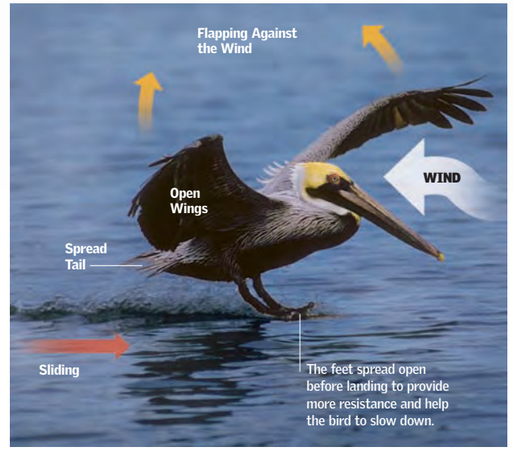
Diagram describing the movements of the tip of the wing during flight

The wings flap 80 times per second during normal flying.

Courtship Display
Certain hummingbird species can flap their wings up to 200 times per second during courtship.

Landing

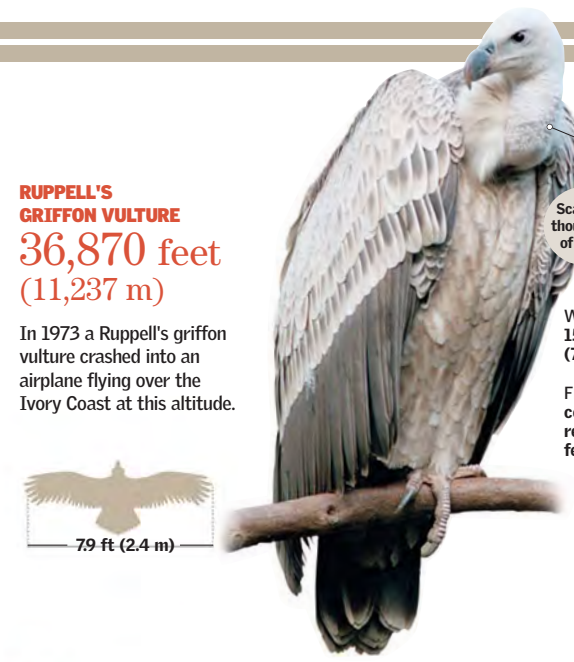
requires reducing speed until the bird becomes motionless and settles. The bird faces the wind and spreads out its tail, wings, and alulae (bastard wings, characterized by their stiffness and growth from the first digit), while lifting up its body and extending its legs forward to increase the surface area in contact with the air. In addition, the bird flaps its wings intensely in the direction opposite to its flight. Everything works like an aerodynamic brake. Some birds—such as the albatross, with its long, narrow wings—tend to have problems slowing down. As a result, they are ungainly when landing on the ground, but on the water they are able to ski on their feet until coming to a stop.



Speed Records

The world of birds is amazing when expressed in numbers. Most birds travel at speeds between 25 and 45 miles per hour (40–70 km/h), but when diving, peregrine falcons can reach more than 200 miles per hour (320 km/h). Many species can reach an altitude of 6,600 feet (2,000 m), although climbers have seen geese flying over the Himalayas at more than 26,000 feet (8,000 m). The fastest swimmer is the Gentoo penguin, which can swim 22.4 miles per hour (36 km/h). Considering its small size, it is surprising that the *Selasphorus rufus*, or Rufous hummingbird, which is only 4 inches (10 cm) long, carries out an extensive round-trip migration each year from northern Alaska to Mexico. Here are some more incredible facts.

RUPPELL'S GRIFFON VULTURE
36,870 feet (11,237 m)
In 1973 a Ruppell's griffon vulture crashed into an airplane flying over the Ivory Coast at this altitude.



Weight **15-20 pounds (7-9 kg)**

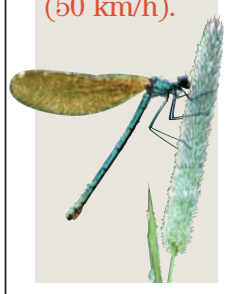
Flying Altitude **commonly reaches 20,000 feet (6,000 m).**

Air

SPEED

Most birds fly between 25 and 45 miles per hour (40 and 70 km/h), but the fastest birds can beat the cheetah, the most famous of the fast animals.

DRAGONFLY
The fastest flying insect. It reaches 31 mph (50 km/h).



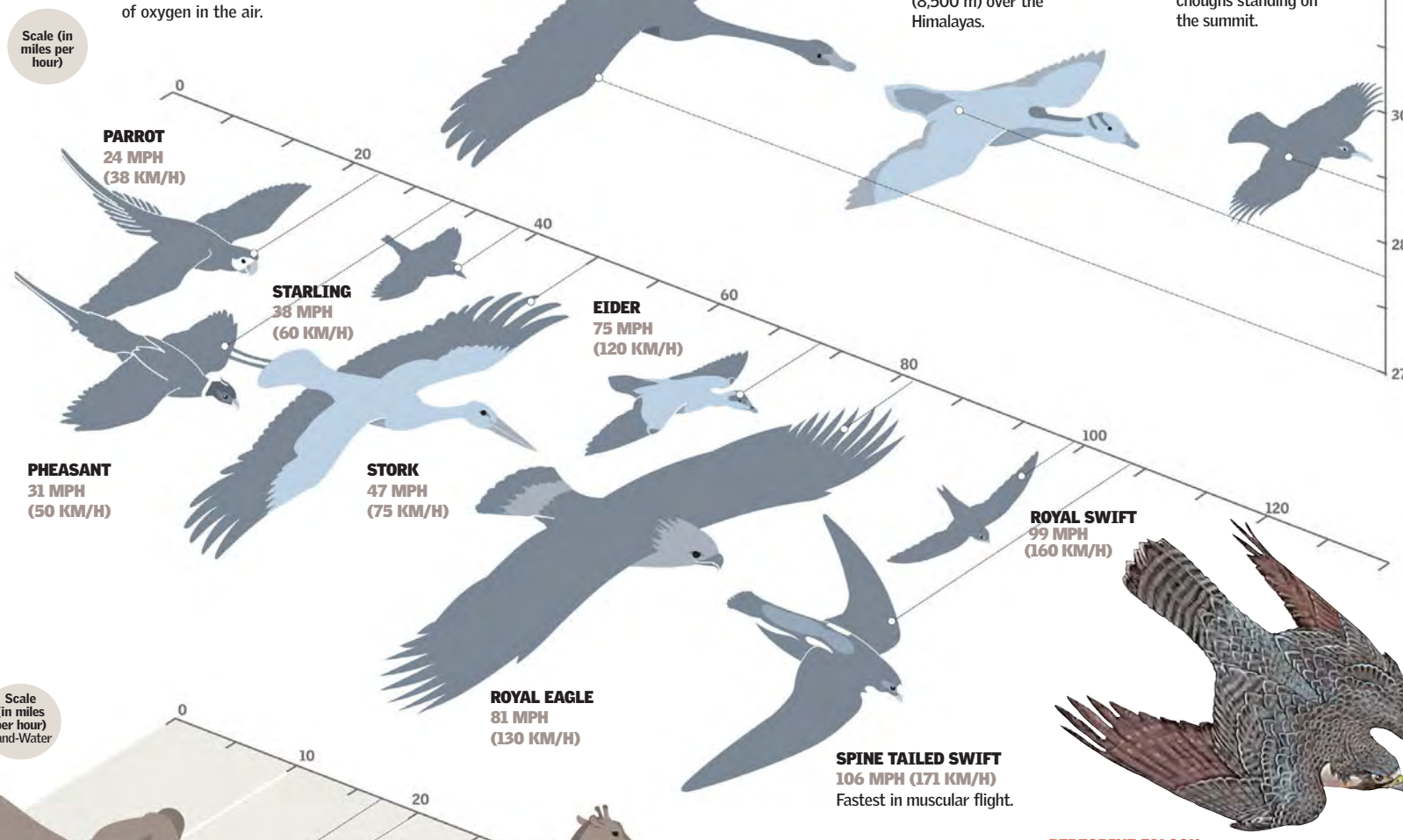
ALTITUDE

Flying at high altitudes requires a strengthened circulatory system to make up for the scarcity of oxygen in the air.

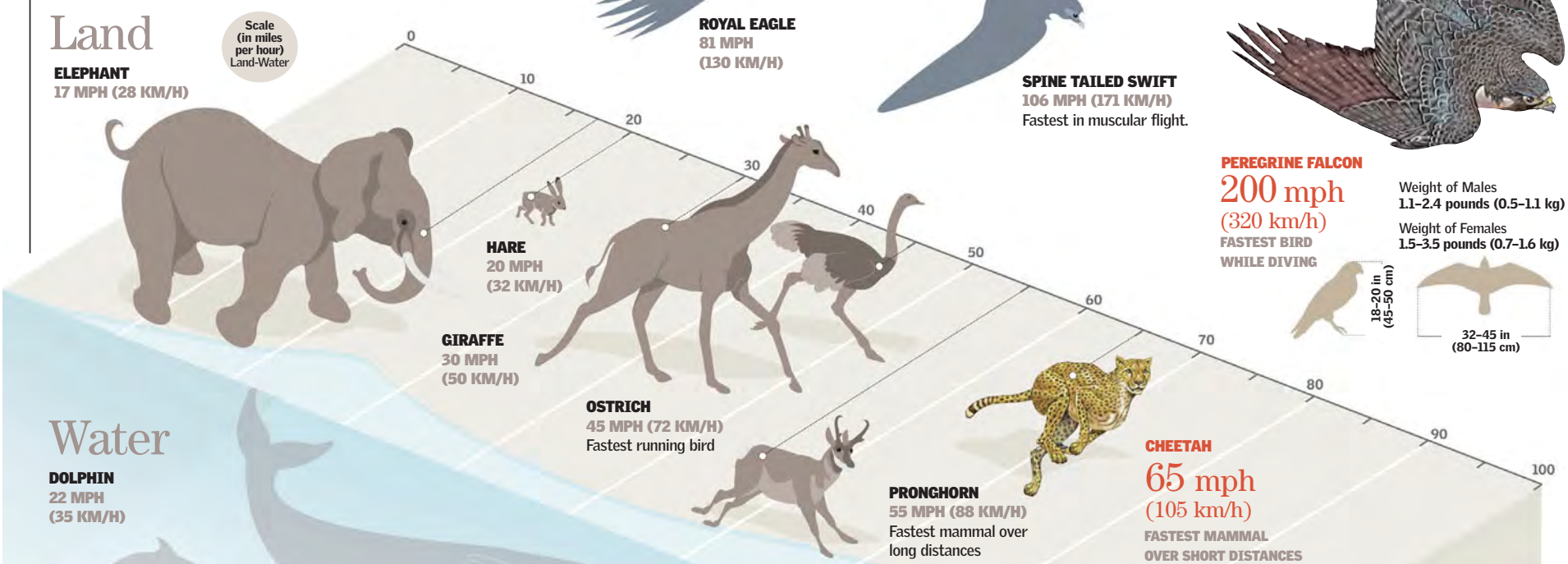
BLACK SWAN
27,000 FEET (8,230 M) OF ALTITUDE,
according to a pilot who witnessed a flock over the Hebrides Islands

BAR-HEADED GOOSE
28,000 FEET (8,500 M)
Some climbers reported having seen specimens of geese flying at 28,000 feet (8,500 m) over the Himalayas.

CHOUGH
29,030 FEET (8,848 M)
A group of climbers on Mt. Everest found choughs standing on the summit.



Land

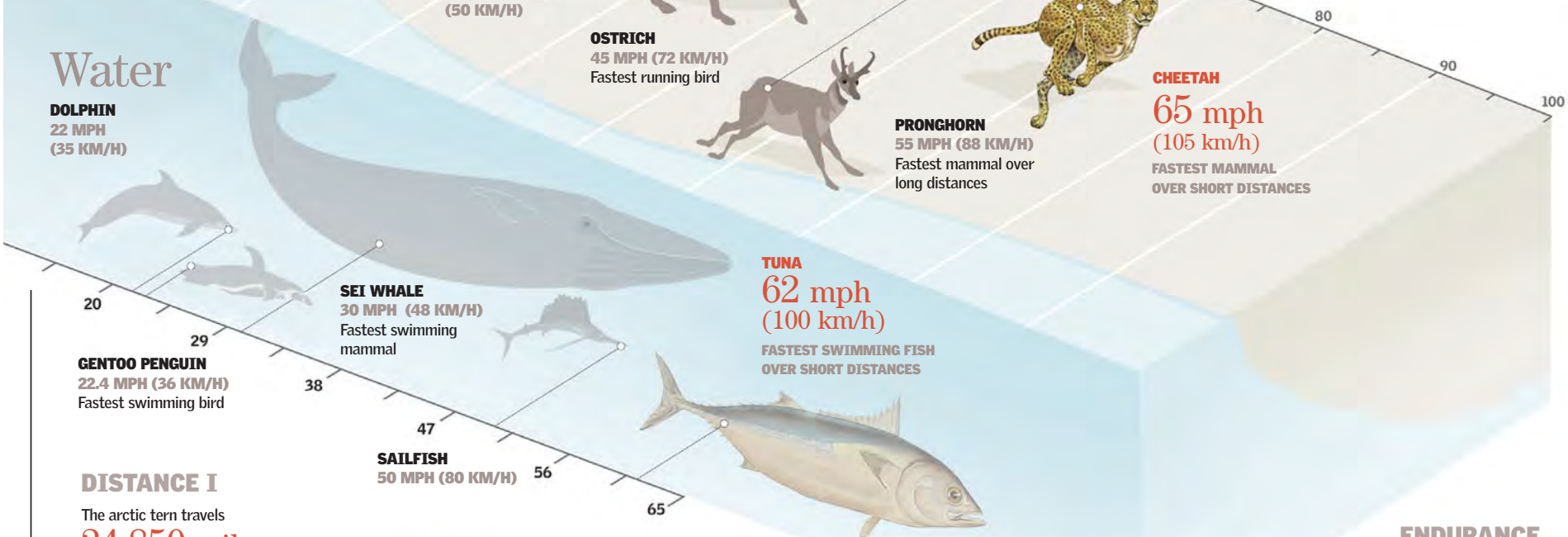


PEREGRINE FALCON
200 mph (320 km/h)
FASTEST BIRD WHILE DIVING

Weight of Males **1.1–2.4 pounds (0.5–1.1 kg)**

Weight of Females **1.5–3.5 pounds (0.7–1.6 kg)**

Water

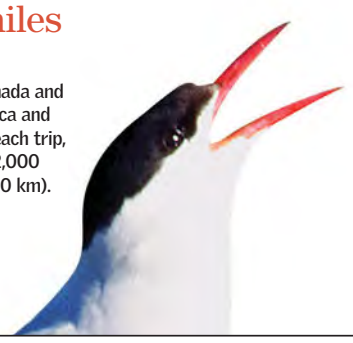


DISTANCE I

The arctic tern travels 24,850 miles (40,000 km).

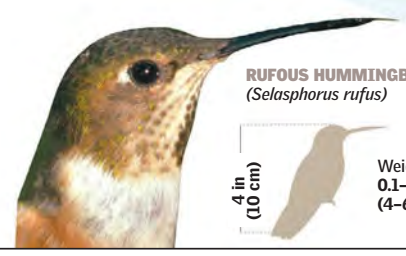
It migrates from Canada and Labrador to Antarctica and the Austral Sea. On each trip, it travels 9,000 to 12,000 miles (15,000–20,000 km).

ARCTIC TERN
(Sterna paradisea)



DISTANCE II

The Rufous hummingbird flies from northern Alaska to Mexico and back—a journey of 6,000 miles (10,000 km/h).



RUFOUS HUMMINGBIRD
(Selasphorus rufus)

Weight **0.1–0.2 ounce (4–6 g)**

ENDURANCE

The endurance record goes to the golden plover, which is able to fly a distance of 1,900 miles (3,000 km) without stopping.

GOLDEN PLOVER
(Pluvialis apricaria)

The Lives of Birds

PARTRIDGE EGGS *(Lagopus lagopus scoticus)*
The female lays eggs at intervals of one to two days, and she is the one who incubates them.

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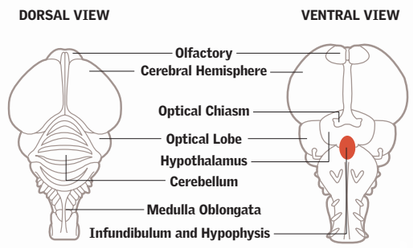
The behavior of birds is closely connected to the seasons. To survive, birds must prepare for the arrival of fall and winter and adjust their behavior accordingly. Gliding over the oceans, a wandering albatross, for example, can travel anywhere from 1,800 to 9,300 miles (2,900 to 15,000 km) in a single day in search of food. When the time comes to choose a partner, the behavior of males is different from that of females: males employ a variety of tactics to win over females and convince them of their fitness. Some bird couples stay together forever, whereas other birds change partners every year. As for caring for chicks and building nests, in most species both parents participate.●

The Annual Cycle

The annual cycle of seasons is like the daily cycle of night and day. Fluctuations in the intensity of light over time create a series of physiological and behavioral changes in birds, whether throughout the year or throughout the day. This biological clock is clearly reflected in birds' reproduction and migrations. Changes in light that are detected by a bird's retinas induce the secretion of melatonin by the pineal gland. The blood level of this hormone acts on the hypothalamus-hypophysis axis, which regulates internal processes. This is one reason why birds start to change their plumage and feel the need to fly to other areas.

How the Hypophysis Works

Reproduction is the main activity under the control of the hypophysis, which determines behaviors such as finding a place to court females and mate, building a nest, incubating the eggs, and stimulating unborn chicks to break their shells. The hypophysis is a gland in the brain that has several functions. It receives nervous and chemical stimuli and produces hormones. These hormones regulate the metabolic activities that cause birds' internal and external sexual organs to develop. For example, the gonads become enlarged, and secondary sexual characteristics, such as ornamental crests or plumes, appear.



Sleep Regulator

The pineal gland, or epiphysis, produces melatonin. The level of this hormone determines the phases of sleep and wakefulness.

THE MOST IMPORTANT GLAND

The hypophysis is located in the ventral area of the brain, below the hypothalamus. Its secretions control vital functions, from blood pressure and the balance of water and salts in the body to the activity of the gonads and the thyroid.

Survival Manual

Birds' most striking behaviors are associated with the reproductive season. During courtship parades, birds engage in elaborate choreographies; there are also extraordinary fights between males. The blue-footed booby, the male frigate bird, and the ruff are just a few examples of birds that engage in these behaviors. Others, such as the snowy egret *(Egretta thula)*, prefer to offer twigs for the construction of the nest. The Vogelkop bowerbird *(Amblyornis inornata)* builds bowers with leaves, flowers, or any other object that may help him to win over the female. Birds' performances are not connected only to courtship. The killdeer *(Charadrius vociferus)* fakes being wounded to defend the eggs or chicks in the nest from predators. It offers itself as easy prey by dragging a wing as if it were broken. This trick shifts the danger away from the young.

SHOWING OFF

The magnificent frigate bird *(Fregata magnificens)* is a large bird that lives in coastal areas. It has large wings, powerful talons, and a strong hooked bill. During the reproductive season, it is responsible for building the nest. With its impressive appearance, it endeavors to attract a female.

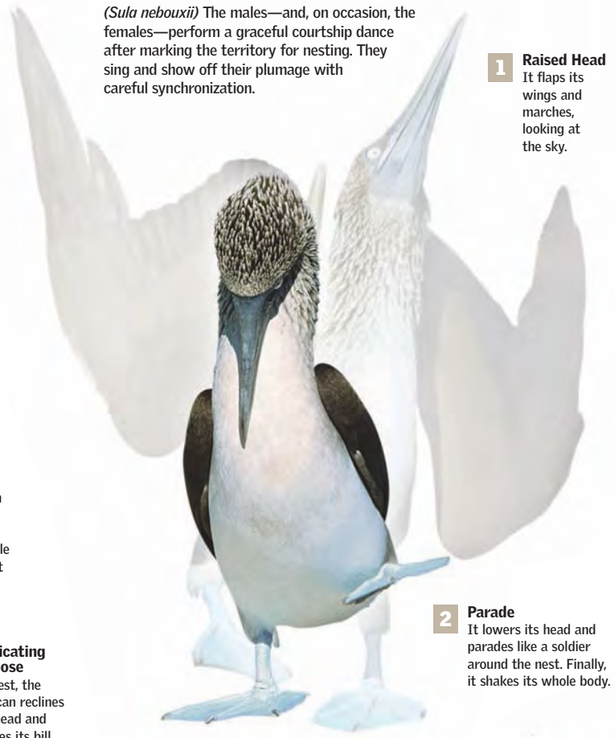
New House
While it prepares the nest, its chest rests, with its skin pink and relaxed.

Red Chest
The throat pouch remains inflated for several hours or until the female chooses the most seductive male.

Indicating Repose
To rest, the pelican reclines its head and places its bill under a wing.

DANCE OF THE BLUE-FOOTED BOOBY

(Sula nebouxii) The males—and, on occasion, the females—perform a graceful courtship dance after marking the territory for nesting. They sing and show off their plumage with careful synchronization.



1 Raised Head
It flaps its wings and marches, looking at the sky.

2 Parade
It lowers its head and parades like a soldier around the nest. Finally, it shakes its whole body.

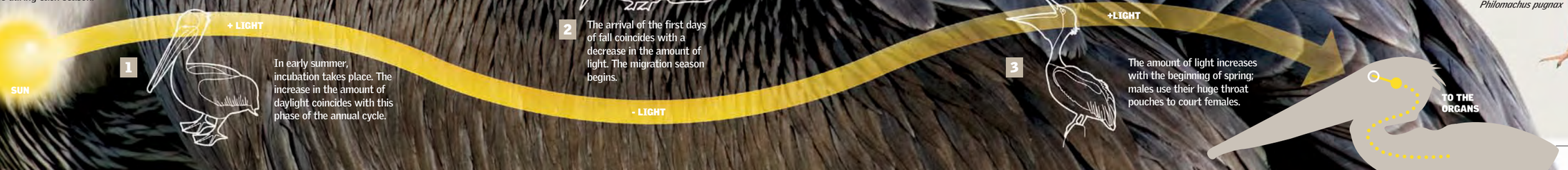
IN COMBAT

In the summer, male ruffs develop a huge "ruff" and auricular feathers around their necks. Their courtships are violent and striking. When competing for mating territory, they struggle fiercely. Afterward they docilely sprawl their bodies on the ground until the female chooses the lucky one.

Male Ruff
Philomachus pugnax

ANNUAL CYCLE

Incubation, migration, and courtship activities vary according to the amount of light available during each season.



1 In early summer, incubation takes place. The increase in the amount of daylight coincides with this phase of the annual cycle.

2 The arrival of the first days of fall coincides with a decrease in the amount of light. The migration season begins.

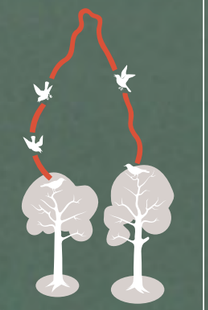
3 The amount of light increases with the beginning of spring; males use their huge throat pouches to court females.

How They Communicate

Sound is an important form of expression in the lives of birds. Birds' sounds can be of two types: calls and songs. The former have a simple acoustic structure, with few notes. They are associated with coordinating the activities of a group, establishing communication between parents and their young, and maintaining contact between birds during migration. Songs, on the other hand, are more complex in rhythm and modulation. They are controlled by the sex hormones, primarily the male hormones. For this reason, males produce the most varied melodies. Songs are linked to sexual behavior and territorial defense. In general, birds either inherit or learn them.

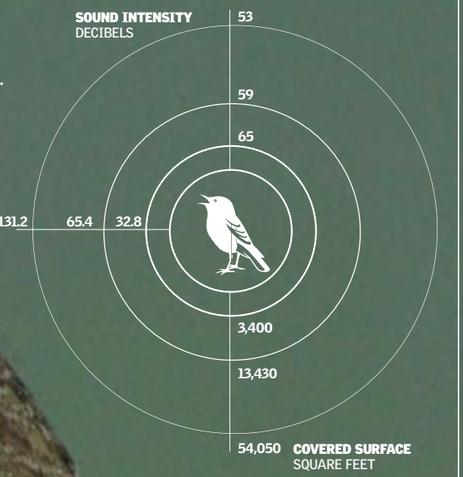
Territoriality and Range

One of the most studied functions of birds' songs is territorial demarcation. When a bird occupies a territory, it sings to announce its claim to competitors, as the pipit shown to the left is doing. When birds must share territory, as in a colony, they develop dialects (variations of sounds produced by the species). When a bird born and raised in one location moves, it must learn the dialect of the new location in order to be accepted and participate in the community. There are also mechanical sounds produced by wing strokes, legs, and bills. In a display of territorial defense, the eared nightjar combines singing with beating its wings.



4,000 bird species

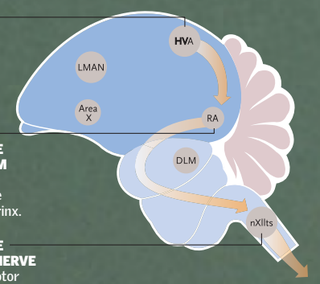
SHARE WITH HUMAN BEINGS AND WHALES THE NEED FOR "SOMEBODY" TO TEACH THEM TO VOCALIZE (SONGBIRDS, HUMMINGBIRDS, AND PARROTS ARE EXAMPLES).



INTENSITY
can vary widely from bird to bird. The larger the territory, the greater its reach. Its frequencies can change as well: the lower the frequency, the greater the coverage.

1 THE SONG AND THE BRAIN

Birds have a brain that is well developed for this function. Testosterone acts on the upper vocal center of the brain, which is in charge of memorizing, identifying, and transmitting the orders for the execution of the song.



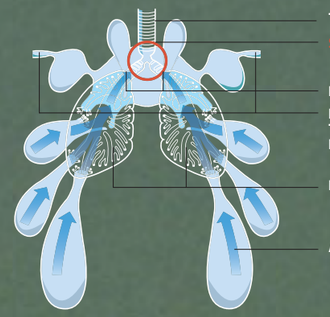
HIGH VOCAL CENTER
It is controlled by the central nervous system and orders the bird to sing.

ROBUST NUCLEUS OF THE ARCHISTRIATUM
It sends the information to the muscles of the syrinx.

NUCLEUS OF THE HYPOGLOSSAL NERVE
It controls the motor functions of the syrinx.

2 EXPULSION OF AIR TO THE BRONCHI

The air stored in the air sacs and lungs is expelled. As it passes through the syrinx (located between the bronchi and the trachea), it vibrates the tympaniform membranes. These membranes are the equivalent of vocal cords in humans.

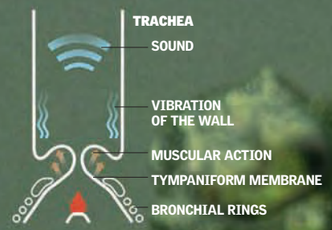


3 THE PRODUCTION OF SOUND IN THE SYRINX

The participation of both the sternotracheal muscles and five to seven pairs of small internal muscles is needed for producing sounds. These muscles control the elongation and contraction of the syrinx, which varies the pitch of the sound. The air sac is also important because it adds external pressure, which causes the tympaniform membranes to tighten. The esophagus works like a resonating box, amplifying the sound. The articulation of the sounds occurs in the buccopharyngeal cavity. There are two types of articulation: guttural and lingual.

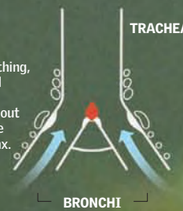
SIMPLE SYRINX

The tympaniform membranes are located above the place where the bronchi divide. They are moved by a pair of external muscles.

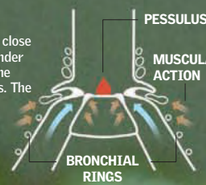


SONG-PRODUCING SYRINX

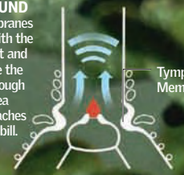
A AIR AND BRONCHI
During breathing, the songbird maintains airflow without affecting the resting syrinx.



B CLOSED MEMBRANE
The membranes close on both sides, under pressure from the external muscles. The bronchi rise slightly and also adjust the membranes.

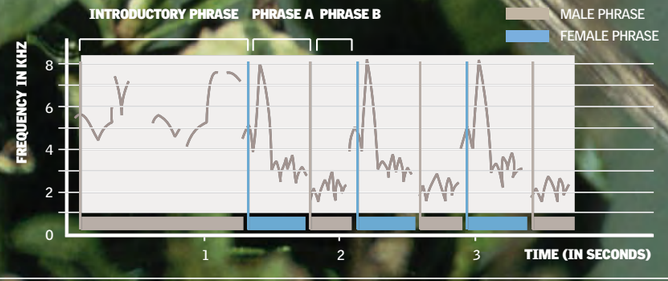


C THE SOUND
The membranes vibrate with the air current and propagate the sound through the trachea until it reaches the bird's bill.



Strengthening Ties

Some songbirds develop very complex singing rituals. The duet is perhaps the most striking because it requires both a shared repertoire and good coordination between both birds. In general, the male initiates the song with a repeated introduction; the female then alternates with different phrasing. The phrasing allows for more or less cyclical variations that make it unique. It is believed that this strengthens ties between the pair (as demarcation of territory does) and serves as a stimulus for cooperative behaviors, such as nest building, in which both the male and female may participate.



Nuptial Parade

Finding a mate is not easy for any species. For birds, the exhibition of plumage with bright colors, the presentation of offerings and gifts, and the performance of dances and highly elaborate flight patterns are some of the particular behaviors seen during this period. They are known as nuptial or courtship displays. The male resorts to all these strategic gestures to attract the female's attention and prevent her from paying attention to other males. Some of these rituals are extremely complicated; others are very tender and delicate.

TIMING

The courtship display is directly related to reproduction cycles. It takes place before copulation, although it can continue to occur thereafter.

Prenuptial
Prenuptial courtship starts with territorial establishment and the search for a partner, which can take place simultaneously.

Postnuptial
With this display, the great crested grebe ensures the continuity of the pairing even after the eggs are laid.

5.9 feet (1.8 m)

IS THE SIZE OF THE TAIL OF THE PEACOCK WHEN IT UNFURLS ITS MORE THAN 200 SHINING FEATHERS AND FORMS A FAN TO ATTRACT THE FEMALE.

Gray Crowned Crane
Balearica regulorum
Two cranes perform a courtship dance consisting of a series of impressive leaps.

A
When its sexual arousal peaks, the male northern harrier *(Circus cyaneus)* flies in a wavelike pattern to attract the female.

B
During courtship, the male northern harrier pretends to attack the female.

AERIAL EXHIBITIONS
Certain birds, such as goshawks or male northern harriers, court the female in flight. They ascend in the air in broad circles, only to let themselves fall in daring, sharp dives.

MUTUAL DANCES AND COURTSHIPS
Great crested grebes *(Podiceps cristatus)* perform incredible aquatic dances. They bow to each other, dive, and run through the water side by side.

Special Courtship

Avian courtship is a phenomenon that, depending on the species, can take the form of various rituals. Lek rituals are one of the most intriguing forms of courtship. The males gather in a small area, called an arena, where they perform their courtship displays for the females. The females form a circle around the arena and end up mating with the male that has the most striking secondary sexual characteristics. Lek is a system controlled by the dominant male, who ends up mating with most of the females (polygyny). The less experienced males will mate with only a few, or even none, of the females. For some species, lek rituals can be very intricate. At least 85 species perform this special type of courtship ritual, among them manakins, pheasants, cotingas, and hummingbirds. Manakins, for example, stand in line and wait their turn to perform.

DISPLAYING PHYSICAL ATTRIBUTES
To find a partner, birds such as the snowy egret resort to a series of very elaborate signals, such as songs, poses, dances, flight patterns, noisemaking, and displays of their ornamental feathers.

BUILDING BOWERS
Australian bowerbirds build a structure called a bower, which they decorate with pieces of paper and fabric that inevitably attract the female.

GIFTS
Another courtship strategy is the presentation of gifts. Male eagles give females prey, and European bee-eaters offer insects. These offerings are called courtship food.

Emperor Penguin
Aptenodytes forsteri
A monogamous species. Each recognizes its partner by its voice, and couples will spend their entire lives together.

Monogamy or Polygamy

Monogamy is the most common mating system, in which two birds, one of each sex, participate, leading to the formation of a couple. This couple can endure for a single reproductive season or for life. Polygamy is an alternative pattern, but it is not very common. Polygamy is divided into two classes: polygyny, in which the male mates with several females, and polyandry, in which the female mates with several males (and may even be able to keep them all together in a harem). In either case, one partner has the sole responsibility of caring for the eggs and chicks. There is also an exceptional case within polygamy: promiscuity. In this arrangement, a couple is not formed, and the relationship is limited to copulation.

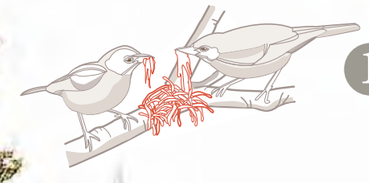
Home Sweet Home

Most birds lay their eggs in a nest, where they are incubated by the body heat of an adult sitting on them. To build a nest, the couple normally uses mud mixed with saliva, small stones, branches, and feathers. When the nest is in a visible location, the bird covers it with lichens or loose twigs to hide it from predators. Nest shapes vary according to the bird group: they can take the form of a bowl, a hole in a tree (woodpeckers), or an excavated burrow on a slope of sand or soil. There are even birds that use nests built by other species.

How the Nest Is Built

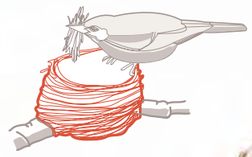
A cup-shaped nest is built at a fork between two or three branches. The bird arranges twigs, grass blades, and small sticks, as if building a platform. The bird then interlaces some of these materials with the tree to give the nest solidity. It then interweaves the materials in a circular pattern. As the nest takes shape, lighter, more adhesive materials—such as mud, spiderwebs, caterpillar silk, and certain plant fibers—are used. Although the outside is rough, the inside is lined with feathers for softness and warmth. In general, if both the male and female participate in the construction, a few hundred trips are enough to complete the nest. In some species, such as weavers, males have to display a nest during courtship; in others (African black eagles, for instance), the same nest is used every year.

THE LITTLE MASKED WEAVER builds solid nests, weaving together leaves and grass blades. Sometimes the male builds several nests before the female chooses him.



1 BASE
The bird gathers branches and small sticks on a fork to lay the foundations of the nest, setting up a platformlike structure. The bird then ties it to the tree, making it sturdy.

2 SHAPE
The bird intertwines grass blades, small sticks, and hairs; fastens them; and gives them a circular shape. As construction advances, the bird uses adhesive materials, such as spiderwebs.



3 END
The finish includes moss and feathers to smooth out the interior and provide insulation against the wind and cold, which makes the nest more suitable for incubation.

BASE
This is the nest's foundation, and it is the first section built by the bird. It is solid and is usually built with bulkier materials.

WALLS
Eare the most important component in a nest's construction, and they give it its characteristic shape. The materials used vary, depending on the habitat.

LINING
It is composed of fibers, hairs, feathers, and down. It insulates the eggs from the cold and helps with incubation.

Structure

The cup shape is important for preventing eggs from rolling out and falling. Besides making the construction of the nest easier, the use of different materials helps make the nest sturdier, as the smaller and more flexible pieces firm up the base, walls, and lining of the structure. Different materials also provide more efficient insulation, keeping warmth in and cold out during the incubation and raising of chicks. As an added reinforcement, birds usually make the side facing the prevailing winds thicker and the side facing the sun thinner. Thus, the whole nest is an incubator that conserves energy. Finally, an exterior finish camouflages the nest among branches, hiding it from predators.

SOME VARIATIONS

WOVEN NESTS
Weaver birds intertwine grass blades until they form a structure. The entrances are underneath.

BURROWS
Parrots and kingfishers dig their nests in sandy river banks.

PLATFORM NESTS
The sparrow hawk gathers a large number of branches and assembles a high, solid base for its eggs.

SEWN NESTS
The tailorbird sews two large leaves together with grass blades. The nest is inside the leaves.

Types and Locations

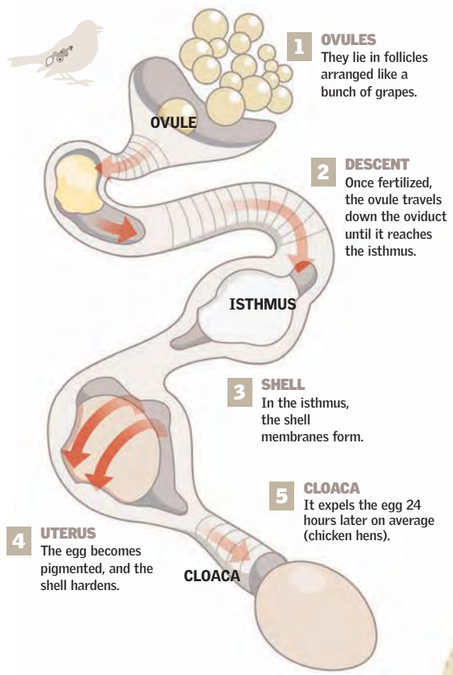
Nests are classified according to their shape, material, and location. They vary depending on the amount of warmth the species needs, as well as in terms of the level of protection they offer. The greater the pressure from predators, the higher or better hidden a nest must be. Good examples are isolated nests resembling high platforms; nests in deep depressions in the soil or hidden in tree trunks, which are very safe and provide good insulation; and nests made of clay, which are very hard. The most typical nests resemble a cup and are found at various locations, most often between two or three high, remote branches.

First, the Egg

Birds may have inherited their reproductive method from their predecessors, the theropod reptiles. In general, they lay as many eggs as they can care for until the chicks become independent. Highly adapted to the environment, the eggs of the same species have varying shapes and colors. These variations help keep them safe from predators. They also vary greatly in size: the egg of an ostrich is 2,000 times bigger than that of a hummingbird.

How It Forms

Birds have only one functional ovary, the left one, which grows dramatically during the mating season. The ovule can descend and form what are known as unfertilized eggs (the type used in cooking). If the egg is fertilized, embryonic development begins. The ovule, fertilized or not, descends to the cloaca in a few hours or days. The eggshell begins to be formed at the isthmus, through the secretion of calcium. At first soft, the shell hardens when it comes in contact with the air.



1 OVULES
They lie in follicles arranged like a bunch of grapes.

2 DESCENT
Once fertilized, the ovule travels down the oviduct until it reaches the isthmus.

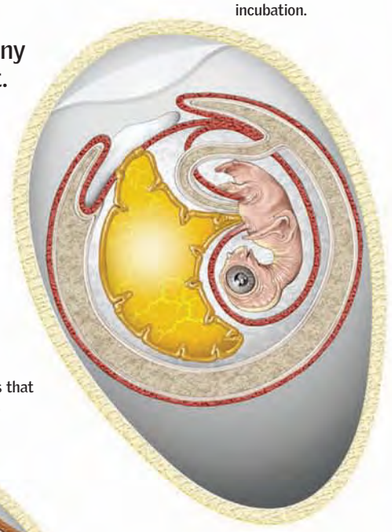
3 SHELL
In the isthmus, the shell membranes form.

4 UTERUS
The egg becomes pigmented, and the shell hardens.

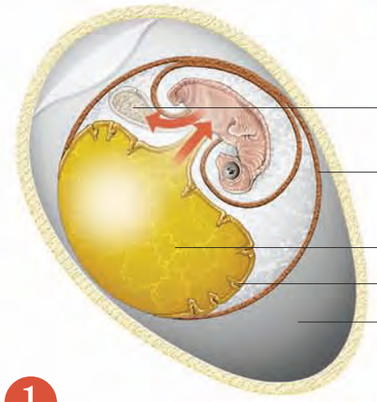
5 CLOACA
It expels the egg 24 hours later on average (chicken hens).

LAYING
A group of eggs laid at one time is called a laying. During the mating season, a sparrow can have several layings. If some eggs are removed, the sparrow can replace them without difficulty.

3 Most birds' organs are formed in the first hours of incubation.

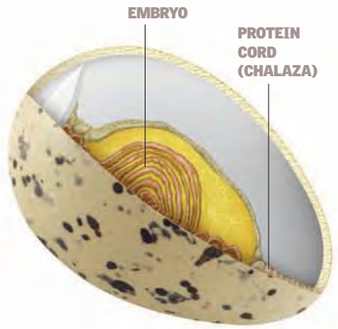


2 As it feeds to grow, the embryo produces wastes that are kept in a special sac.



1

The egg contains an embryo in one side of the yolk. The yolk is held in the middle of the white (albumin) by a protein cord that isolates it from the outside world.



SHAPE

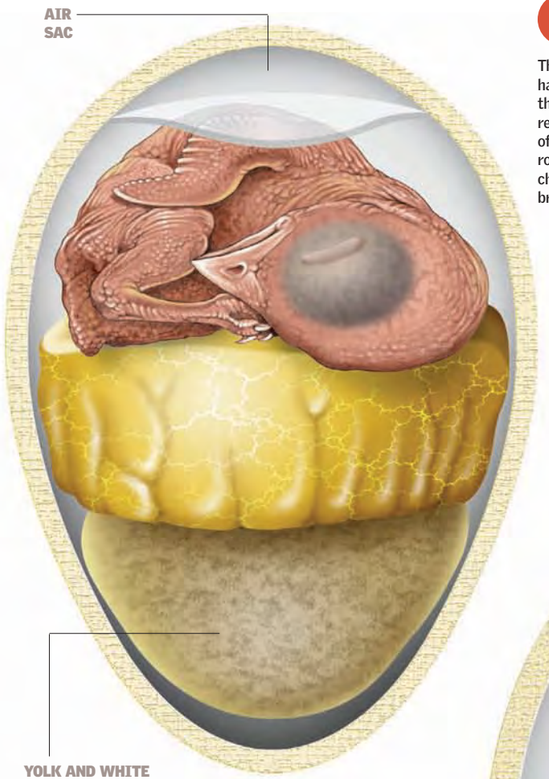
It depends on the pressure exerted by the oviduct walls. The large end emerges first.

Oval: The most frequent | Conical: Prevents falling | Spherical: Reduces the surface area

COLOR AND TEXTURE

Both texture and color help parents locate the egg.

Light Egg | Dark Egg | Speckled Egg



4

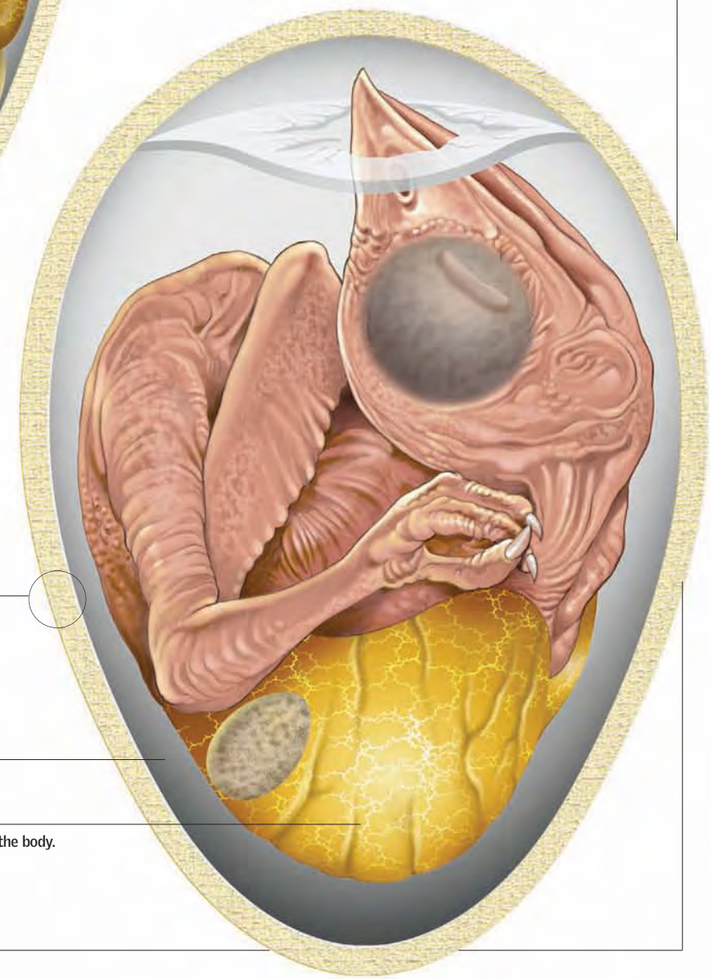
The bill and scales of the legs harden toward the end, when the chick is formed and reaches a size similar to that of the egg. At that point, rotation begins so that the chick will be positioned to break its shell.

SIZE
There is no exact proportion between the size of a bird and its egg.

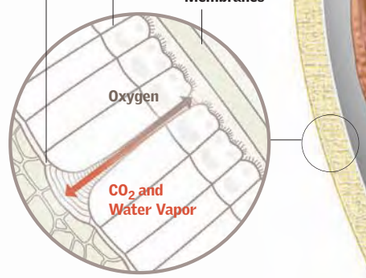
1 lb (500 g) — Kiwi Egg
2 oz (60 g) — Chicken Hen's Egg

5

When the chick is ready to break the shell, it is taking up all the space inside the egg. The chick is cramped with its legs against its chest. This enables it to open the shell with small movements and with the help of a hard point at the tip of its bill (called an egg tooth).



THE SHELL
Formed by a solid layer of calcium carbonate (calcite), it has pores that make it possible for the chick to breathe. Bacteria are kept out by two membranes that cover the egg, one on the inside and the other on the outside.



8%
THE PROPORTION OF AN EGG TAKEN UP BY THE EGGSHELL

ALBUMIN
was consumed.

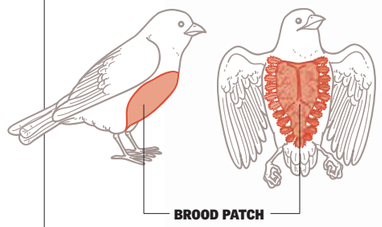
YOLK
disappears into the body.

Birth in Detail

When a chick is about to hatch, it starts to make itself heard from inside the egg. This allows it to communicate with its parents. It then starts to peck at the shell with its tiny egg tooth, which is lost after birth. Next, it turns inside the egg and opens a crack with new perforations, at the same time pushing with its neck and legs until it manages to stick out its head. This job demands a lot of effort and can take 30 to 40 minutes or, in the case of kiwis and albatrosses, even three to four days. In most species, newborn chicks are blind and naked, and they can open their bills only to receive food.

INCUBATION

For the embryo to develop, it needs constant temperatures between 99° and 100° F (37-38° C). The parents ensure these temperatures by sitting on the eggs and warming them with their brood patches.



During incubation, some species lose their chest feathers and increase their number of blood vessels in this area. Others pluck out their feathers. Direct contact with the eggs helps keep them warm.

DURATION BY SPECIES
The incubation period varies considerably: between 10 and 80 days, depending on the species.

PIGEON
Females and males incubate. They both develop a brood patch.
18 days

PENGUIN
Both males and females incubate. The emperor male has a special pouch for incubation.
62 days

ALBATROSS
Lacking brood patches, the parents hold the egg between their feet and abdomen.
80 days

Adaptations for Hatching

Getting out of the egg is an intricate operation because the space is tight, and a chick's muscles have little vigor. Birds count on a few adaptations, such as the egg tooth and the hatching muscle, to accomplish the task. The tooth is used for making the first perforation, which allows air into the egg. The muscle exerts the necessary strength, while stimulating the chicken's motor functions to intensify the effort. Both the egg tooth and the hatching muscle disappear shortly after the eggshell is broken.

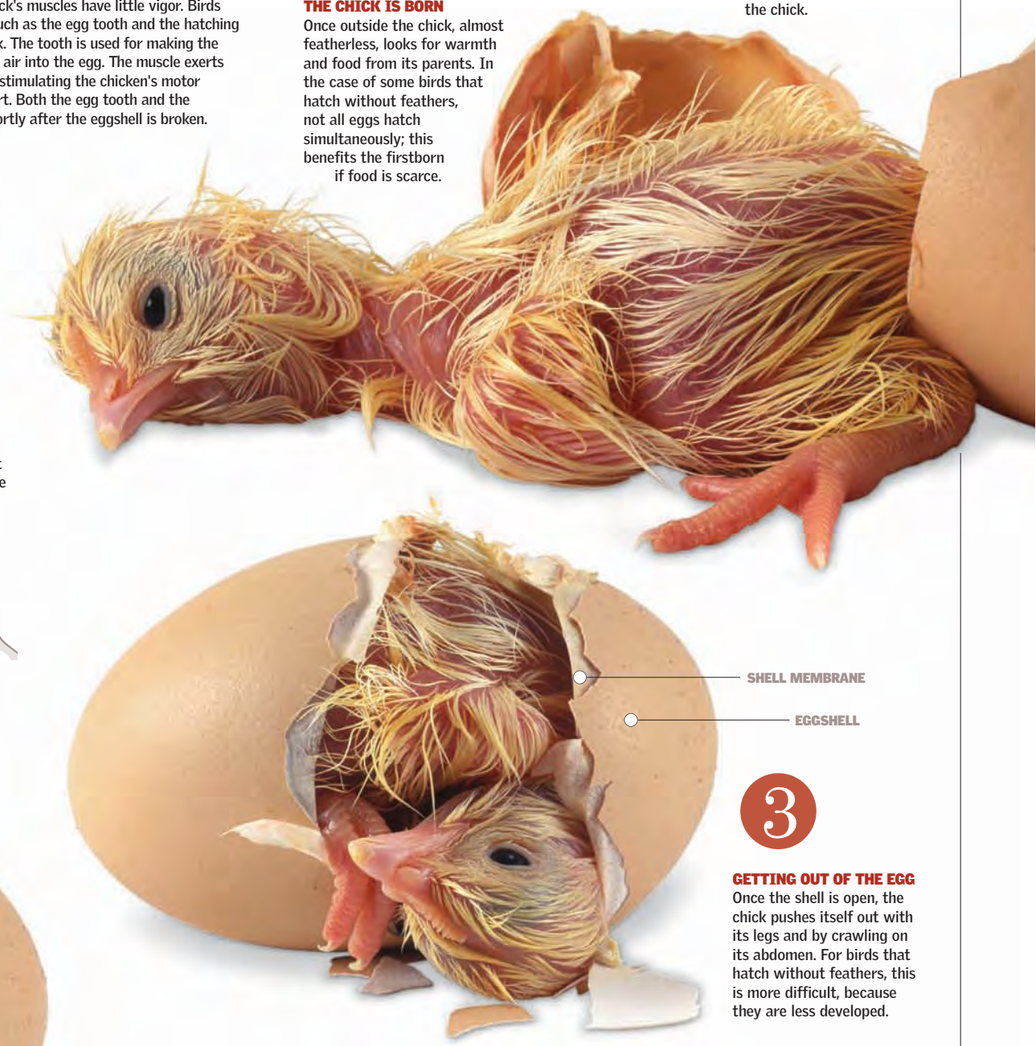
HATCHING MUSCLE
It exerts pressure against the shell and helps to break it.

EGG TOOTH
A protuberance on the bill that punctures the egg. Its presence depends on the species.

4

THE CHICK IS BORN
Once outside the chick, almost featherless, looks for warmth and food from its parents. In the case of some birds that hatch without feathers, not all eggs hatch simultaneously; this benefits the firstborn if food is scarce.

A GREAT EFFORT
Getting out of the shell requires much energy from the chick.



3

GETTING OUT OF THE EGG
Once the shell is open, the chick pushes itself out with its legs and by crawling on its abdomen. For birds that hatch without feathers, this is more difficult, because they are less developed.

Breaking the Shell

This process may take from a few minutes to three or four days, depending on the species. In general, the parents do not intervene or help their young. When the shell is empty, they throw it out of the nest, apparently to avoid attracting the attention of predators. In species whose young hatch with the feathers already developed, hatching is extremely important. It has been observed that the singing of the chicks stimulates the stragglers and delays those that have gotten ahead; it is important that they all be ready to leave the nest together.

35 minutes
IS THE APPROXIMATE TIME IT TAKES A SPARROW TO COME OUT OF THE EGG.

1

CRACK IN THE EGG
The chick turns inside until its bill targets the egg's midline. It then punctures the air sac. With a few more tries, it pierces the shell. The chick then breathes for the first time.

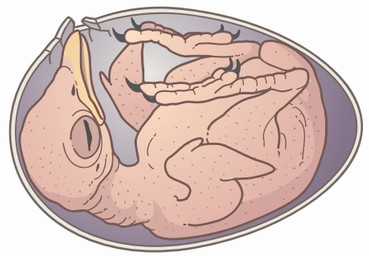
ASKING FOR HELP
The chick calls for its parents from inside. The reply encourages it to continue the effort.

SEQUENCE OF PECKING
Between each sequence of pecking, the chick must take long breaks.

2

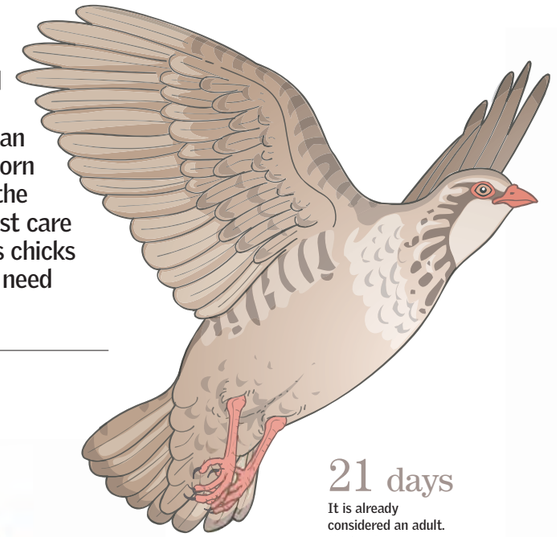
THE CRACK EXPANDS
After making a hole in the shell, the chick opens a crack with successive pecks at other points. Air gets in and dries up the membrane, which makes the task easier.

WHAT COMES OUT FIRST?
The head usually comes out first, because the sharp bill helps break the shell. Most birds then get out of the egg by pushing themselves out with their legs. For wading birds and other terrestrial birds, however, the wings usually unfold first.



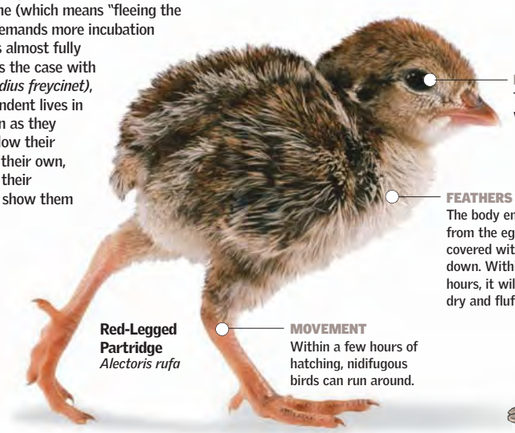
Postnatal Development

Chicks develop at highly variable rates after hatching. Some birds are born with their eyes open and with a thick layer of down feathers. These birds can also feed themselves. That is why they are called precocious, or nidifugous. Ducks, rheas, ostriches, and certain beach birds can walk and swim as soon as they are born. Other species are born naked and develop their feathers later. They need to stay in the nest until they have sufficiently developed, so adult birds must care for them. These birds are called nidicolous. The most helpless chicks are the young of songbirds and hummingbirds, because they need warmth from their parents to grow strong. ●



Nidifugous Young

Nidifugous young are fully developed at the moment of birth. They can move and even leave the nest, hence their name (which means "fleeing the nest"). This adaptation demands more incubation time because the chick is almost fully developed at birth. This is the case with incubator birds *(Megapodius freycinet)*, which begin their independent lives in the outside world as soon as they leave the shell. Ducks follow their parents but find food on their own, whereas chickens follow their parents, and the parents show them where to find food.



EYE
They are born with open eyes.

FEATHERS
The body emerges from the egg covered with damp down. Within three hours, it will become dry and fluffy.

Red-Legged Partridge
Alectoris rufa

MOVEMENT
Within a few hours of hatching, nidifugous birds can run around.

GROWTH STAGES

30 hours
The chick keeps warm with the down that covers its body. It can walk and begins to be fed by its parents.

7 to 8 days
Growth quickens, and the first covert feathers appear at the tip of the wing. The bird leaves the nest. Its diet consists of:
66% invertebrates.
The rest consists of seeds and flowers.

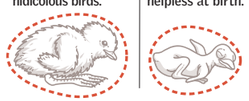
21 days
It is already considered an adult. Its flights are longer. Its diet is composed of 97 percent vegetables; the rest is made up of lichens and insects.

15 days
It starts to perform short flights. It reverses its diet, eating:
66% seeds and flowers.
The rest consists of invertebrates.

24 hours
IS THE MINIMUM AMOUNT OF TIME THE BLACK-HEADED DUCK NEEDS TO BE READY TO FLY.

SIZE COMPARISON

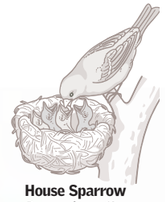
NIDIFUGOUS	NIDICOLOUS
The egg is larger, the chick is born more developed, and the incubation period is longer than that of nidicolous birds.	They lay small eggs, with a brief incubation period, and the young are helpless at birth.



Nidicolous Broods

Most of these chicks are born naked, with closed eyes and with only enough strength to get out of their shells. They stay in the nest. For the first few days, they cannot even regulate their own body temperature; they need their parents in order to stay warm. Within one week, they have a few feathers, but they require constant care and food. They form a numerically important group that includes Passeriformes (songbirds).

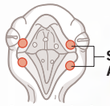
FOOD
They need much food to develop. The parents must feed them 24 hours a day.



House Sparrow
Passer domesticus

An adult bird can feed its young up to **400 times a day.**

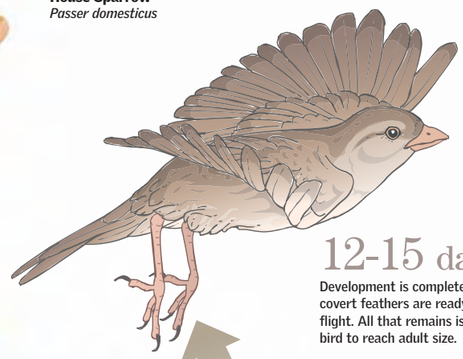
INTERIOR OF THE BILL
Its color is bright to stimulate the parents to regurgitate the food.



Shining Areas
Some species have shiny areas that can be seen even in the dark.

EYES
Nidicolous chicks are born blind. They open their eyes a few days after birth.

FEATHERS
The chicks are born either naked or with down feathers in some areas.

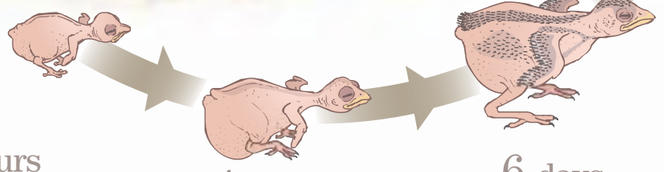


12-15 days
Development is complete, and the covert feathers are ready for flight. All that remains is for the bird to reach adult size.

10 days
Feathers cover everything, but they are not yet developed. The chick can stay warm on its own, and it is voracious. Growth is very fast.

8 days
Feathers cover the chick almost completely, except around its eyes. Its legs are well developed, and the sparrow moves around in the nest.

STAGES OF GROWTH



25 hours
It performs a few instinctive movements. It can barely raise its head to ask for food.

4 days
The eyes open. The tips of the first feathers appear. It performs a few movements.

6 days
Some feathers begin to unfold, the nails are formed, and the wings continue to grow with the body. It can stand up.

12-15 days
IS THE ESTIMATED TIME THAT IT TAKES THIS NIDICOLOUS CHICK TO LEAVE THE NEST.

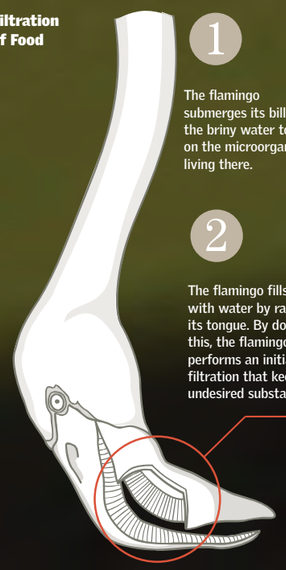
A Diet for Flying

Most birds eat assorted foods that are rich in energy and proteins. Their high level of activity requires that they eat almost constantly. Their sources of food are varied and include seeds, fruits, nectar, leaves, insects and other invertebrates, and meat of all kinds (including carrion). Many species eat more than one type of food; some even alternate according to the seasons and to the migration cycle. This guarantees their survival. However, there are others birds—a minority—that consume only one type of food, for which they have no competition. Because their dependence on this single source of food is greater, though, the risk is higher. Feeding behavior also varies among different species. For example, some eat alone, and others eat in groups.

A Complex System

Feeding on microorganisms that live in salty water demands a complex filtration system. The flamingo's bill is specially suited to this task. Its tongue and throat pump the water inside the bill as they ascend and descend, bringing water through the hornlike lamellae, which resemble whale baleen, to retain the food passing through them. Their tongues also have a depressed area, where the stones and sediments that come in with the water collect. The whole operation requires that the flamingo submerge its bill upside down. Because of the number of microorganisms they need to consume and the time it takes to filter them, flamingos usually spend many hours in the water. The risks involved in this activity are mitigated by the fact that flamingos do not eat alone, but rather in groups. Occasionally, there are instances of aggression, possibly because of territorial conflicts.

Filtration of Food

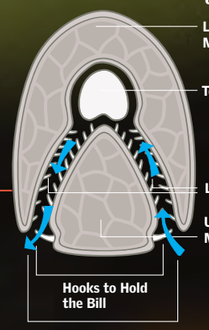


1 The flamingo submerges its bill in the briny water to feed on the microorganisms living there.

2 The flamingo fills its bill with water by raising its tongue. By doing this, the flamingo performs an initial filtration that keeps out undesired substances.

3 A second filtration occurs inside the bill, as the water is expelled. The lamellae (small plates) catch the microorganisms but let water and other matter pass.

Cross-Section of the Bill



From Parents to Children

Flamingos and pigeons feed their young a special "milk" that is produced in the crop and has a nutritional value similar to the milk of mammals. Both males and females produce it as soon as food is ingested so that the chick is not fed regurgitated food.

1. The flamingo produces milk in its crop only when it is not eating. A protein called prolactin participates in its preparation, just as with mammals.

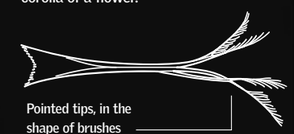
2. It is given to the young through the bill. Easy to digest and nutritious, it is an excellent food.

3. This milk has high concentrations of the pigment that colors the feathers; that is why the bird's color changes to the characteristic pink while molting in adolescence.

Types of Diet

Birds expend a great deal of energy, and their diet must be suited to their high metabolic rates. They eat practically anything, although the diet of some birds is very specific. The same foods are not always available, which causes most birds to adjust their diets throughout the year.

THE HUMMINGBIRD'S TONGUE
Long channeled or tubular tongues suck the nectar and catch insects at the bottom of the corolla of a flower.



NECTAR
is a solution of sugar and water that flowers produce. It is very high in energy and easy to digest. In order to get it, a bird must have a long, sharp bill. In temperate regions, nectar is plentiful in the spring and summer, whereas in the tropical regions, it is available year round. Hummingbirds and honeycreepers are very fond of this juice.

SEEDS AND GRAINS
The high energy and protein content of seeds make them an ideal food for birds. The problem is that they are seasonal.

MEAT
Hunting and scavenging birds feed on meat. They rarely specialize in one type of prey, but the prey's size determines its selection.

FISH
The abundance of fish throughout the year makes them one of the favorite foods of marine birds. They have a high nutritional value.

LEAVES AND PLANTS
Few birds feed on leaves because they have low energy value. Birds that do have undergone adaptations that permit them to digest cellulose.

FRUIT
In the tropics, this diet is very common because fruits are available throughout the year. In temperate and cold regions, fruit can be found only in the summer. Fruit has a high energy value, and many birds eat it.

INSECTIVORES
Insects are rich in energy and proteins, and they are highly abundant. Thus, many bird species eat them. In cold regions, they can be found only in the summer.

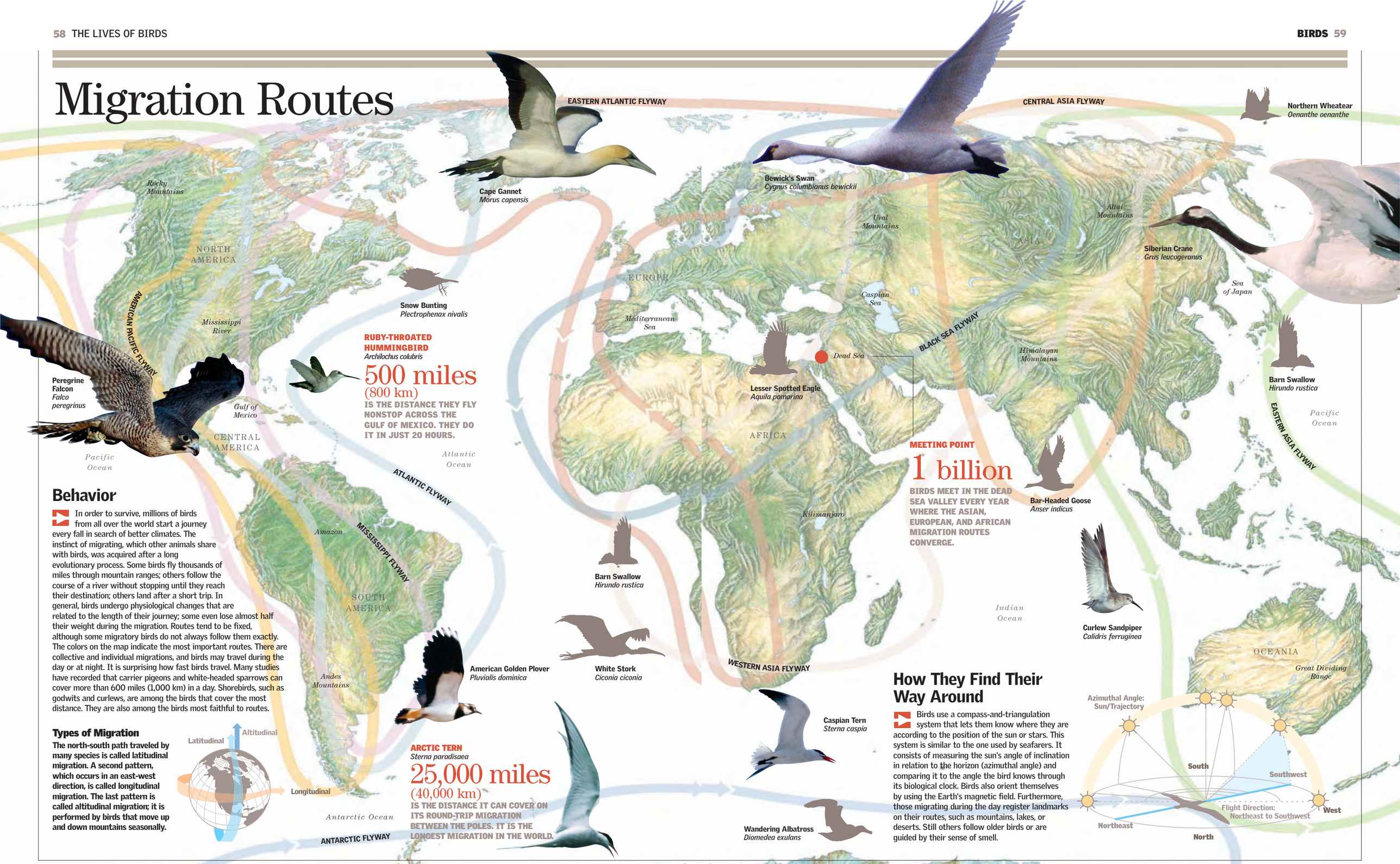
Strategies

Depending on the abundance of resources, the needs of the species, and the strategies for getting food, birds may eat alone or in groups. If food is scarce or widely scattered throughout a region, birds eat alone and defend their territory. On the other hand, if food is abundant, they prefer to eat within the safe confines of the group.

SOLITARY
Usually birds of prey, such as eagles and owls, hunt alone because food is scarce and is randomly distributed. Hunting alone has a drawback in that birds must also watch out for predators, which takes time away from hunting.

TOGETHER
This behavior is typical of ocean birds, such as pelicans and seagulls, and of aquatic birds, such as flamingos. When birds eat in groups, each group member can warn the others about possible dangers, which is beneficial.

Migration Routes



Behavior

In order to survive, millions of birds from all over the world start a journey every fall in search of better climates. The instinct of migrating, which other animals share with birds, was acquired after a long evolutionary process. Some birds fly thousands of miles through mountain ranges; others follow the course of a river without stopping until they reach their destination; others land after a short trip. In general, birds undergo physiological changes that are related to the length of their journey; some even lose almost half their weight during the migration. Routes tend to be fixed, although some migratory birds do not always follow them exactly. The colors on the map indicate the most important routes. There are collective and individual migrations, and birds may travel during the day or at night. It is surprising how fast birds travel. Many studies have recorded that carrier pigeons and white-headed sparrows can cover more than 600 miles (1,000 km) in a day. Shorebirds, such as godwits and curlews, are among the birds that cover the most distance. They are also among the birds most faithful to routes.

Types of Migration

The north-south path traveled by many species is called latitudinal migration. A second pattern, which occurs in an east-west direction, is called longitudinal migration. The last pattern is called altitudinal migration; it is performed by birds that move up and down mountains seasonally.

How They Find Their Way Around

Birds use a compass-and-triangulation system that lets them know where they are according to the position of the sun or stars. This system is similar to the one used by seafarers. It consists of measuring the sun's angle of inclination in relation to the horizon (azimuthal angle) and comparing it to the angle the bird knows through its biological clock. Birds also orient themselves by using the Earth's magnetic field. Furthermore, those migrating during the day register landmarks on their routes, such as mountains, lakes, or deserts. Still others follow older birds or are guided by their sense of smell.

Defense Strategies

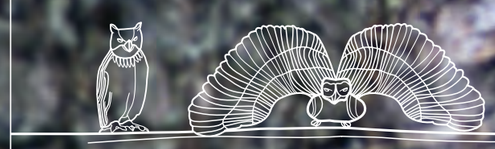
Birds have many predators, including cats, snakes, crocodiles, and other birds. To defend themselves against these predators, birds use various strategies, the most common of which is camouflage. Some birds blend in with their surroundings and thus go unnoticed by their enemies. Chaparral birds, whose plumage colors and patterns make them difficult to discern when they are on the ground, use this strategy. Other birds take flight in the face of a threat. There are also those that keep still in the presence of unknown animals, feigning death, whereas others face an enemy and fight. It is not uncommon to see magpies, thrushes, and other birds chasing away strangers that get close to their nests.

Individual Strategies

Among solitary birds, it is common to flee quickly if a stranger is present. Not all solitary birds react this way, though; some have developed specific techniques to defend themselves.

ESCAPE
In the presence of terrestrial predators, a bird's first reaction is to take flight. If the bird cannot fly, it looks for shelter or a hiding place.

EXPANSION
Owls spread out their wings to look bigger than they really are.



DISTRACTION
Little bustards shoot their excrement in the face of birds that prey on them. This distracts the predator and makes it possible to escape.

CAMOUFLAGE
is very common and is one of the most efficient defensive strategies. Many birds develop plumage to imitate the dominant colors and shapes of the environment where they live. When they notice the presence of a potential enemy, they stay motionless to avoid calling attention to themselves. There are a few notable cases, such as that of the tawny frogmouth *(Podargus strigoides)*, pictured above. Many partridges and terrestrial birds are experts at the art of blending in with the landscape; the rock ptarmigan, for example, has white plumage in the winter that becomes terra-cotta in the summer.

Collective Strategies

Birds that have group behaviors usually develop group strategies to protect themselves against predators. Being numerous is a guarantee that the species will go on. They also adopt other tactics as a group.

COLONIES
A great number of birds can defend themselves better from predators when in groups. For that reason they even form colonies with other bird species when raising their young.

FLOCK
In the presence of predators, birds form flocks that fly in a synchronized manner, which makes it hard for the predators to focus on any one individual.

ATTACKS AND COLLECTIVE AID
Many birds that live in groups have developed several hounding behaviors in the presence of potential enemies. They perform them to help an individual that is in danger or is unable to flee.

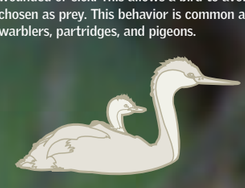
WARNING
They emit callings that warn the whole colony. The great majority of species have a specific and characteristic cry that is usually simple, brief, and very audible.
They often emit these warnings while adopting postures (such as stretching the neck or shaking the wings) that alone are enough to warn other individuals of the intruder's presence.

Defense of the Brood

Hatching and youth are times of critical vulnerability for birds. During these phases, they are forced to keep still because they are easy prey. For this reason, parents permanently watch over their nests, even attacking strangers if they get too close.

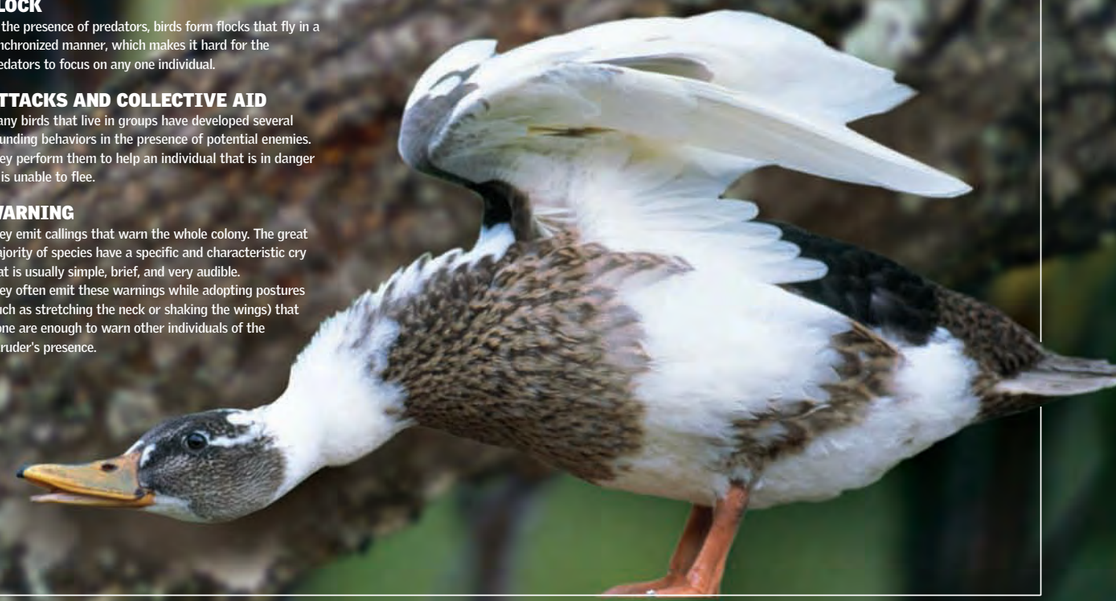
FEIGNING INJURY
A very widespread behavior is to pretend to be wounded or sick. This allows a bird to avoid being chosen as prey. This behavior is common among warblers, partridges, and pigeons.

ATTACK
In other situations, birds adopt openly aggressive behaviors in the presence of intruders or predators. Magpies can even hound and chase away eagles if the latter threaten their brood. Such active defenses are more common among birds of prey.



PROTECTION
When a parent detects danger, it gets close to its young and covers them so that they are not alone. This behavior is common among tropical birds (tropical seabirds). Several species of curlews and sandpipers place their young between their legs, whereas grebes carry their chicks on their backs when swimming.

TO DEFEND ITSELF from the falcon's attack, a flock of starlings squeezes together in a dense formation. If they are near a tree, they do not hesitate to hide in it.



Diversity and Distribution

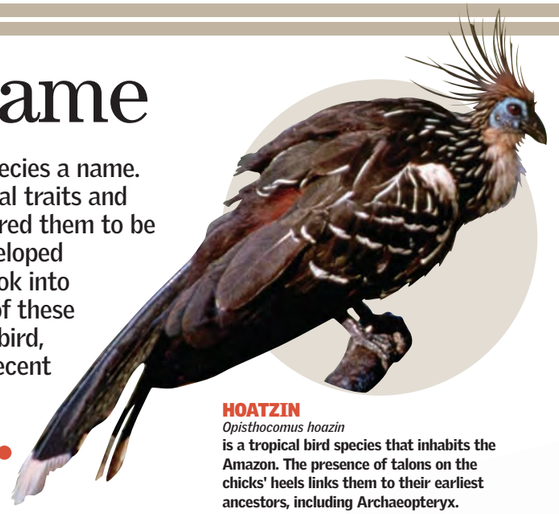
DUCK (Anatidae family)
A natural-born fisher, ducks feed on small snails and aquatic insect larvae.

ONE BIRD, ONE NAME 64-65
WHERE THEY LIVE 66-67
NO FLYING ALLOWED 68-69
MARINE RESIDENTS 70-71
FRESHWATER BIRDS 72-73
ARMED TO HUNT 74-75
TALKATIVE AND COLORFUL 76-77
THE PERCHERS CLUB 78-79

The environment in which an organism usually lives is called its habitat. In their habitats, birds find food, the best places to build nests, and escape routes in case of danger. An almost universal pattern of distribution shows that more species live in the tropics than elsewhere. With evolution, birds with a common origin have diversified as they have begun to occupy different environments. This phenomenon is called adaptive radiation. We find ocean birds, which have undergone many changes in order to live near the sea, as well as birds that live in freshwater environments, in forests, and so on. Each type has acquired special physical traits and behaviors as a result of the adaptive process. ●

One Bird, One Name

To learn more about different birds, we give each species a name. Ancient peoples grouped birds according to practical traits and mystical beliefs. They used birds as food or considered them to be bad omens or symbols of good luck. The people who developed scientific thought created a classification system that took into consideration the external form as well as the behavior of these vertebrates; hence, the denominations predator, wading bird, and songbird were developed, among others. The most recent system of classification, which is based on genetic and evolutionary criteria, has generated a hierarchical organization of names that is constantly being updated.



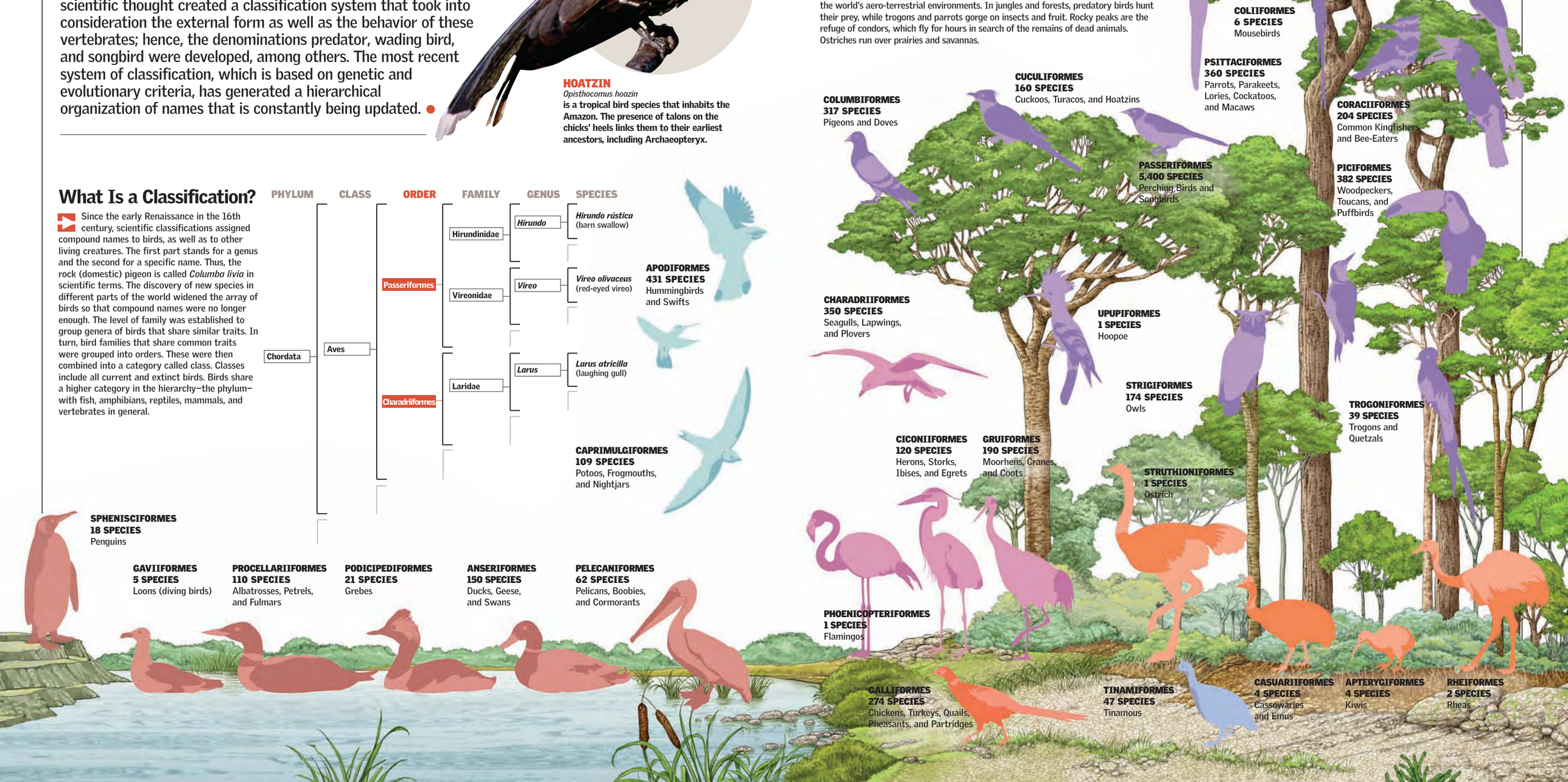
HOATZIN
Opisthocomus hoazin
is a tropical bird species that inhabits the Amazon. The presence of talons on the chicks' heels links them to their earliest ancestors, including Archaeopteryx.

What Is a Classification?

Since the early Renaissance in the 16th century, scientific classifications assigned compound names to birds, as well as to other living creatures. The first part stands for a genus and the second for a specific name. Thus, the rock (domestic) pigeon is called *Columba livia* in scientific terms. The discovery of new species in different parts of the world widened the array of birds so that compound names were no longer enough. The level of family was established to group genera of birds that share similar traits. In turn, bird families that share common traits were grouped into orders. These were then combined into a category called class. Classes include all current and extinct birds. Birds share a higher category in the hierarchy—the phylum—with fish, amphibians, reptiles, mammals, and vertebrates in general.

Diversity and the Environment

Living birds are distributed among a wide variety of habitats. They can be found in aquatic (freshwater or marine) and aero-terrestrial environments. Marine birds live on cliffs, on islands, or in mangrove swamps. They are excellent fishers, and they use seashores or crannies between rocks as refuges for nesting. In freshwater bodies, such as rivers and streams, ducks feed on plants and surface microorganisms. Muddy shores are rich in insects and mollusks, which are the favorite dishes of ibis. Herons, storks, and egrets spear fish with their sharp bills as they wade in water with their long legs without getting wet. Forests, jungles, mountain ranges, and wide plains form most of the world's aero-terrestrial environments. In jungles and forests, predatory birds hunt their prey, while trogons and parrots gorge on insects and fruit. Rocky peaks are the refuge of condors, which fly for hours in search of the remains of dead animals. Ostriches run over prairies and savannas.

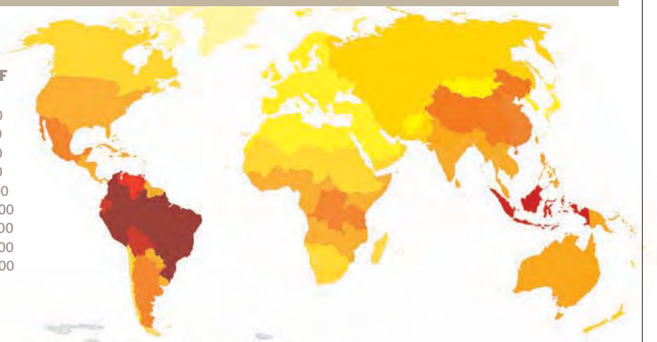


Where They Live

With their mobility, birds have conquered all areas of the Earth. Despite this characteristic, there are few cosmopolitan species—that is, most birds have specific habitats determined by climate and geographic features. Count de Buffon in the 18th century was the first person to notice that living beings are not distributed homogeneously. By analyzing how animals were dispersed on the planet, he realized that different places had different types of fauna. After the work of naturalist Charles Darwin and ornithologist Philip Sclater, it became clear that organisms are situated in specific biogeographic regions.

Biodiversity in the World

The most diverse regions in terms of bird populations are the tropics because of the favorable conditions of abundant food and warm climate found in them. Temperate regions, however, with their seasons, are destinations for migrating birds from tropical and polar regions. Cold regions, on the other hand, have little diversity but are rich in population density. The rule is that diversity of life-forms happens in places where the environment requires less severe adaptations.



PUFFIN
Fratercula artica

NORTH AMERICA

Atlantic Ocean

Pacific Ocean

CENTRAL AMERICA

SOUTH AMERICA

EUROPA

ASIA

AFRICA

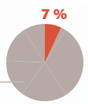
Indian Ocean

Pacific Ocean

OCEANIA

Nearctic

732 Species
62 Families



CHARACTERISTICS

- Climatic barrier of cold weather and oceanic isolation
- Most migrating species
- Many insectivorous and aquatic birds
- Affinity with Palearctic

Endemic Avifauna: **loons and puffins**

Palearctic

937 Species
73 families

CHARACTERISTICS

- Climatic barrier of cold weather and oceanic isolation
- Low diversity of species
- Most are migratory species
- Many insectivorous and aquatic birds

Endemic Avifauna: **wood grouse, waxwings, flycatchers, cranes**

Because of similar climatic conditions, many authors merge the Palearctic and Neoarctic regions, calling the combined region Holarctica.

Oceania

187 Species
15 Families

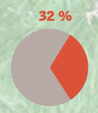
CHARACTERISTICS

- Large area and number of climates
- Gliders, divers, and swimmers
- Abundance of fish-eating species
- Many cosmopolitan species

Endemic Avifauna: **albatrosses, sheathbills, petrels, penguins, and seagulls**

Neotropic

3,370 Species
86 Families



CHARACTERISTICS

- Long-lasting geographic isolation
- Many primitive species
- Great numbers of frugivores

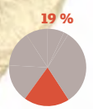
Endemic Avifauna: **rheas, tinamous, oilbirds, hoatzins, cotingas, and stripe-backed antbirds**

This region undoubtedly has the greatest diversity of birds. The variety in the South American tropics, the most important tropical zone in the world, is one and a half times greater than that of tropical Africa. With more than 1,700 species, Colombia, Brazil, and Peru are the countries with the greatest diversity of avifauna. Even Ecuador, a much smaller country, has more than 1,500 species.

HOATZIN
Opisthocomus hoazin

Afrotropic

1,950 Species
73 families



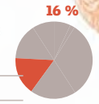
CHARACTERISTICS

- Maritime and desert isolation
- Great number of Passeriformes
- Many flightless birds

Endemic Avifauna: **ostriches, turacos, cuckoos**

Indomalaya

1,700 Species
66 families



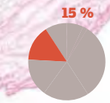
CHARACTERISTICS

- Affinities with the Afrotropical zone
- Tropical birds
- Many frugivores

Endemic Avifauna: **ioras, pittas, swifts**

Australasia

1,590 Species
64 families



CHARACTERISTICS

- Long isolation
- Many flightless and primitive birds

Endemic Avifauna: **emus, kiwis, cockatoos, birds of paradise**

Adaptations According to the Environment

Birds are found in all habitats of the world, although most live in tropical regions. Their ability to adapt, however, is remarkable. From jungles to deserts, from mountains to coasts, and even on the sea, birds have succeeded in acclimating themselves. They have undergone a highly varied array of changes in form and behavior. Emperor penguins not only nest in Antarctica but they also incubate their eggs between their feet for 62 to 66 days. The male Lichtenstein's sandgrouse has developed a sponge of feathers to bring water to its chicks, and hummingbirds have special wings that enable them to make all sorts of maneuvers.

RUBY-THROATED HUMMINGBIRD
Archilochus colubris

OSTRICH
Struthio camelus

COUNTRIES WITH THE MOST SPECIES

More than 1,500

Colombia
Brazil
Peru
Ecuador
Indonesia

More than 1,000

Bolivia
Venezuela
China
India
Mexico
Democratic Republic of the Congo
Tanzania
Kenya
Argentina

No Flying Allowed

A few birds have lost their ability to fly. Their main characteristic is wing loss or reduction, although for some a remarkable size may be the cause of their inability to fly. Such birds weigh more than 39 pounds (18 kg). This is the case with runners (ostriches, cassowaries, emus, rheas, kiwis), extremely fast birds that live in remote areas of New Zealand, and swimmers, such as penguins, that have developed extraordinary aquatic abilities.

AFRICAN OSTRICH
A single species inhabits eastern and southern Africa. Adults reach a height of 9 feet (2.75 m) and a weight of 330 pounds (150 kg).

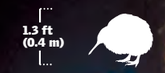
The Ratites

Running birds belong to the group of the ratites (*rata* = raft, an allusion to the flat sternum). The front limbs either are atrophied or have functions unrelated to flying. The hind limbs have very strong muscles as well as sturdy, vigorous bones. Another difference is found in the sternum. It is a flat bone without a keel, which flying and swimming birds possess. Wild ratites can be found only in the Southern Hemisphere. The Tinamidae, native to Central and South America, belong to this group (partridges).

STRUTHIONIFORMES
The ostrich is the only species in this group. It uses its wings for balance when running fast. It has only two toes on each foot. The adult male can weigh up to 330 pounds (150 kg).

RHEIFORMES
Rhea are common in South American countries, such as Argentina. They look like ostriches but are smaller. Their three-toed feet allow them to chase prey. Their long necks and excellent eyesight make them skillful hunters.

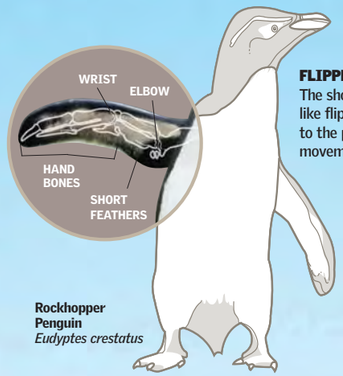
CASUARIIFORMES
Agile runners and swimmers. The colors on their necks and heads are distinctive. A bony hoof protects them from vegetation when they run. They have long, sharp talons on their feet.



APTERYGIFORMES
Kiwis. These birds have four toes on each foot, and their feathers look like fur because they do not have barbules. They normally use their keen sense of smell to find insects at night. They lay only one large egg.

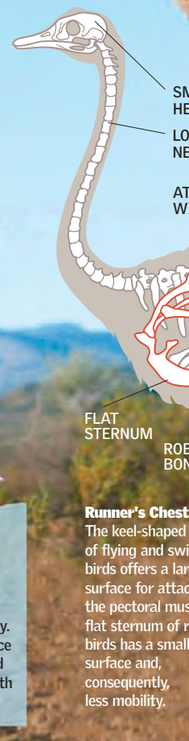
Super Swimmers

Penguins' bodies are covered with three layers of small, overlapping feathers. A penguin has small limbs and a hydrodynamic shape that helps it swim with agility and speed. Dense, waterproof plumage and a layer of fat insulate the bird from the low temperatures of the regions where it lives. Since its bones are rigid and compact, it is able to submerge itself easily. This adaptation distinguishes it from flying birds, whose bones are light and hollow.

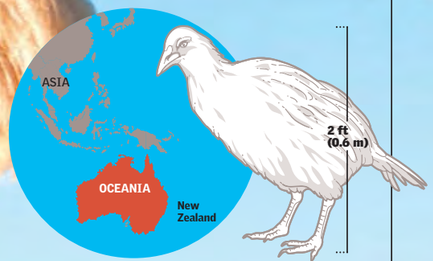


FLIPPERS
The short, compact wings look like flippers. They are essential to the penguin's underwater movements.

Rockhopper Penguin
Eudyptes crestatus



Runner's Chest
The keel-shaped sternum of flying and swimming birds offers a larger surface for attachment of the pectoral muscles. The flat sternum of running birds has a smaller surface and, consequently, less mobility.



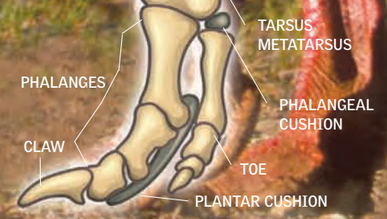
GREATER DIVERSITY
In many cases, running birds can be found in many parts of the world because of human intervention. The area where flightless birds have diversified the most is Oceania, due to continental isolation.

Running and Kicking

Ostriches usually run to escape from predators or to hunt small lizards and rodents. In both cases, because of their strong legs, they are able to reach a speed of 45 miles per hour (72 km/h) and to maintain it for 20 minutes. When running is not enough to protect the bird, kicking is a valid recourse that discourages the attacker. In courtship displays, forceful stamping is also used to win over females.

18
VERTEBRAE
THE NUMBER AN OSTRICH HAS IN ITS NECK

ON TWO TOES
With just two toes, the contact surface between the foot and the ground is relatively small. This is an advantage when moving on land.



Other Walkers

More than 260 species belong to the order Galliformes, which includes chickens, turkeys, and pheasants. The birds in this group have keels, and they perform abrupt and fast flights, but only in extreme situations. Their feet are suitable for walking, running, and scratching the ground. This group includes the birds that human beings use the most. In general, males are in charge of incubating and raising the young.

FLYING WITH LITTLE GRACE

PENGUIN HEADING TO THE WATER

HUNTING
The wings work like flippers. The foot—with four joined toes pointing backward—and the tail steer the direction of the dive.

BREATHING
When looking for food, penguins need to leave the water and take a breath between plunges.

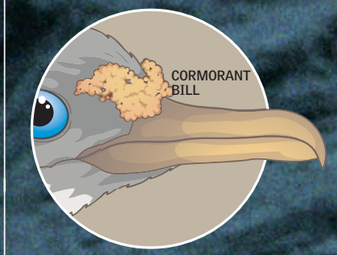
RELAXING
When resting in the water, they move slowly. They float on the surface with their heads up and balance their bodies with their wings and feet.

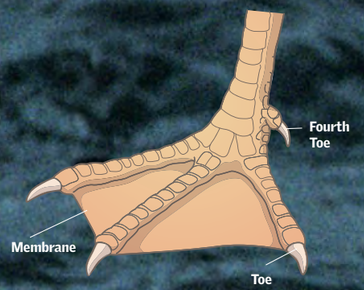
Marine Residents

Of the more than 10,000 bird species inhabiting the Earth, only about 300 have managed to adapt to marine life. To survive at sea, they have undergone multiple adaptations. For instance, marine birds have a more efficient excretory system than that of other species, including a specific gland that helps them eliminate excess salt. Most marine birds live on the coasts and have mixed behaviors; others are more aquatic than aerial. A few—such as albatrosses, petrels, and shearwaters—can fly for months at a time, landing only to raise their chicks. They are called pelagic birds.

Adaptations

Marine birds are well prepared to live on water, especially those that fish out at sea. The tips of their bills are hook-shaped, and their feet have webbed membranes between the toes. They also have an admirable ability to float. The saline water is not a problem; these birds can even drink it. In some pelagic birds, sense of smell plays an important role in enabling them to detect the oil of the fish in the water to find schools of fish. They also use their sense of smell to find their nests in colonies.





TOTIPALMATE FEET
A characteristic of many marine birds. The posterior toe (hallux) is joined to the other toes by a membrane. It creates more surface area, and therefore more push, as the bird swims. Birds with this kind of foot walk clumsily.

148 feet (45 m)
IS THE MAXIMUM DEPTH THEY REACH. COMMON LOONS—BIRDS INDIGENOUS TO NORTH AMERICA THAT SPEND THE WINTER AT SEA—HAVE BEEN RECORDED TO REACH THIS DEPTH. ALMOST UNABLE TO WALK, COMMON LOONS ARE EXCELLENT SWIMMERS AND DIVERS. THEY NEST AT INLAND LAKES DURING THE SUMMER.

COMMON LOON
Gavia immer

VARIOUS MARINE BIRDS

IMPERIAL SHAG
Phalocrocorax atriceps
This great coastal diver has solid bones and strong swimming feet. It does not oil its plumage so that it can better submerge.

BROWN PELICAN
Pelecanus occidentalis
It stays on the shore. It uses its crop as a fishing net while it swims.

HERRING GULL
Larus argentatus
A voracious fisher and great glider. There are many species, some truly cosmopolitan.

CAPE GANNET
Morus capensis
Skillful spearfishers. They live in colonies in Africa. To help cool themselves, they have a strip of naked skin on their throats.

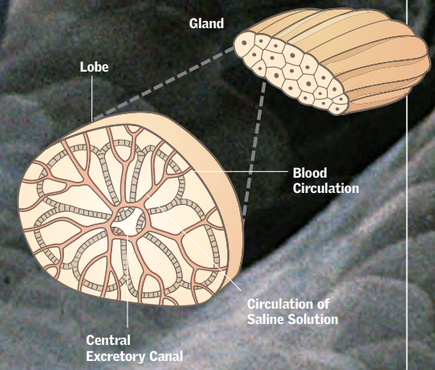
HOOK-SHAPED TIP
Prevents the fish from sliding and falling away, once caught

TUBULAR NOSTRILS
Albatrosses have one on each side of their bills. On petrels and shearwaters, the tubular nostrils have merged on top of the bill, forming a single nasal tube.

BILL
It is composed of several hard plates.

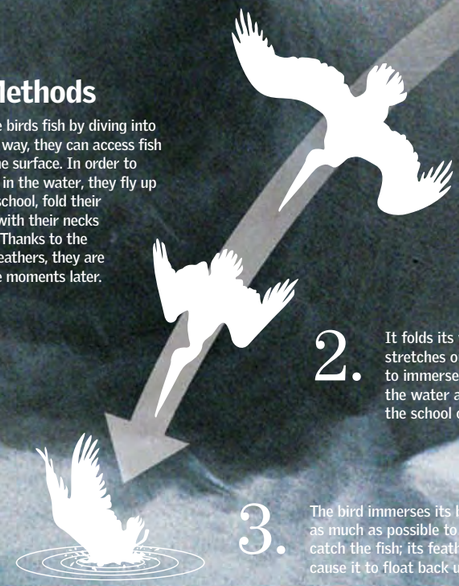
Salt Gland

Living in the ocean requires a few adaptations. The most notable one is the salt gland, which eliminates excess salt from the bloodstream. This way, marine birds can even drink salt water without suffering dehydration, as would be the case with humans. This gland is very efficient: it has been observed that 20 to 30 minutes after drinking a saline solution with concentrations similar to that of the ocean (4 percent), birds eliminate another solution (through the nostrils) with 5 percent salt, in the shape of water drops.



Fishing Methods

Many marine birds fish by diving into the sea. This way, they can access fish that swim below the surface. In order to reach deeper levels in the water, they fly up several feet, spy a school, fold their wings, and plunge with their necks stretched forward. Thanks to the buoyancy of their feathers, they are back on the surface moments later.



DIVE FISHING

1. The bird dives to gain speed.

2. It folds its wings and stretches out its neck to immerse itself in the water and reach the school of fish.

3. The bird immerses its body as much as possible to catch the fish; its feathers cause it to float back up.

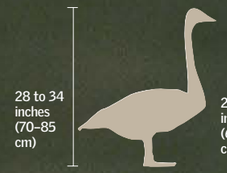
Freshwater Birds

This group includes birds that vary greatly—from common kingfishers to ducks to storks—and covers a wide spectrum. Freshwater birds live in rivers, lakes, and ponds for at least part of the year and are perfectly adapted to aquatic life. Some are excellent swimmers, whereas others are great divers. An important group wades in watercourses with long legs as they fish. Freshwater birds have a varied diet and are mostly omnivorous.

Ducks and Distant Cousins

The order Anseriformes includes birds that are very familiar to humans: ducks, geese, and swans, for example. They have short, webbed feet and wide, flat bills lined with lamellae (false teeth) that enable them to filter their food, catch fish, and scrape the beds of rivers and ponds. Most are omnivorous and aquatic (either staying on the surface or diving), although some species spend more time on land. They are widely distributed, and the plumage of males becomes very colorful during the courtship season.

Muscovy Duck
Cairina moschata

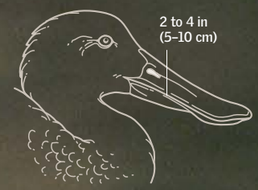


Black-Necked Swan
Cygnus melancoryphus

White-Fronted Goose
Anser albifrons

Fulvous Whistling Duck
Dendrocygna bicolor

DUCK BILLS
are flat, wide, and slightly depressed toward the middle. In general, their shape does not vary, but there are species with tiny bills (the mandarin duck, for example).



Shovel-Shaped Bill:
Typical of many ducks. The size varies.

Mandarin Duck Bill:
One of the smallest-billed species.

Divers and Other Fishers

Diving birds belong to the family Podicipediformes. They feed on small fish and aquatic insects. They are very clumsy on the ground. In the Coraciiformes order, common kingfishers and other similar birds find their prey by closely watching the water. When one of these birds notices a small fish, it spears it, catching it with its bill. In the order Charadriiformes, curlews wander around the edges of ponds in search of food. Their long legs keep their bodies out of the water. They are not swimmers.

GREBE
Podiceps sp.

STONE CURLEW
Burhinus oedicnemus

COMMON KINGFISHER
(also known as European Kingfisher)
Alcedo attlis

THE BILL OF AN IBIS
is long and thin, ideal to stick in the mud to look for food.

Wading Birds

These birds belong to an artificial order since, from a genetic perspective, the species are not related. They are grouped together because adaptation to the same habitat has caused them to develop similar shapes: long bills and necks to perform skillful movements and thin legs designed to wade across the water as they fish. Herons form a special group because they are cosmopolitan and because they have powder down feathers. Ibis and storks also have a wide distribution (area in which they occur). Birds that have spoon- and hammer-shaped bills are found primarily in Africa.

IBIS (*Ibis* sp.): Some filtrate, and others fish.

STORK (*Ciconia* sp.): It fishes with its long bill.

SHOEBILL (*Balae-niceps rex*): It eats among floating sedges.

HERON (*Egretta* sp.): It fishes with its sharp bill.

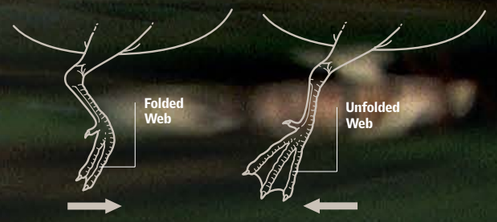
COMMON SPOONBILL (*Platalea leucorodia*): It eats several types of aquatic animals.

HAMMERKOP (*Scopus umbretta*): It fishes and hunts small animals.

White Ibis
Edocimus albus

THE LEGS OF AN IBIS
keep the bird above the water but close enough to fish. Ibis also stir up the beds of lakes and ponds.

HOW THEY USE THEIR FEET TO SWIM
A duck moves its feet in two ways. To advance, it spreads out its toes and uses its webbed feet to row. It closes the toes to bring the foot forward again. If the bird wants to turn, only one foot pushes to the side.



A DUCK'S DIET

1. It swims on the surface, looking for food underneath the water.
2. It sticks its head into the water, abruptly pushes back its feet, and turns its neck downward.
3. It floats face-down and pokes the bottom with its bill.

Armed to Hunt

Birds of prey are hunters and are carnivorous by nature. They are perfectly equipped to eat living animals. Their eyesight is three times sharper than that of human beings; their ears are designed to determine the precise status of their prey; they have strong, sharp talons; and they can kill a small mammal with the pressure of their talons alone. Their hook-shaped bills can kill prey by tearing its neck with a single peck. Eagles, falcons, vultures, and owls are examples of birds of prey. Birds of prey can be diurnal or nocturnal, and they are always on the lookout.

Diurnal and Nocturnal

Eagles, falcons, and vultures are diurnal birds of prey, whereas owls are nocturnal—that is, they are active during the night. These two groups are not closely related. These birds' main prey includes small mammals, reptiles, and insects. Once they locate the victim, they glide toward it. Nocturnal birds of prey are specially adapted: their eyesight is highly developed, their eyes are oriented forward, and their hearing is sharp. The feathers on their wings are arranged in such a way that they make no noise when the bird is flying. In order to protect themselves while sleeping during the day, they have dull plumage, which helps them blend in with their surroundings.

EURASIAN EAGLE OWL
Bubo bubo
Its ears are asymmetrical and can determine the location of prey with great precision.

BALD EAGLE
Haliaeetus leucocephalus
It has a visual field of 220 degrees and a bifocal vision of 50 degrees.

Bills

The bills of birds of prey are hook-shaped. Some birds of prey have a tooth that works like a knife, allowing them to kill their prey, tear its skin and muscle tissues, and get to the food easily. The structure and shape of the bills of birds of prey changes depending on the species. Scavengers (for example, vultures and condors) have weaker bills because the tissues of animals in decomposition are softer. Other species, such as falcons, catch prey with their talons and use their bills to finish it off with a violent stab to the neck, breaking its spine.

CERE
Fleshy formation, somewhat thick and soft

NOSTRIL
Olfactory canals

TIP
Where the tooth is located

Zone-Tailed Hawk
Buteo albonotatus

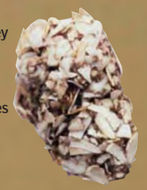
BALD EAGLE
Its hook-shaped bill is common to many birds of prey.

SPARROW HAWK
Its thin bill enables it to take snails out of their shells.

FALCON
It can break the spine of its prey with its upper bill.

GOSHAWK
Its strong bill can catch prey as large as hares.

OWL PELLETS
Owls produce pellets. They swallow their prey whole and regurgitate the indigestible substances. The study of pellets makes it possible to determine the fauna of small areas with great precision.



5 miles (8 km)
IS THE DISTANCE FROM WHICH A FALCON CAN PERCEIVE A PIGEON.

HOW THE VULTURE HUNTS

1. Vultures feed mainly on carrion, although they are able to attack a living animal if it is vulnerable and the situation presents itself.
2. Thanks to their ability to glide on thermals, vultures can find carcasses on which to feed without wasting energy.
3. Once they find food, they must analyze the territory to know if they will be able to take flight again soon.

DIMENSIONS

The wings of birds of prey are adapted to suit their flying requirements. They can measure up to 10 feet (3 m).

Condors 3 to 9.5 ft (0.95–2.9 m)

Eagles 4.5 to 8 ft (1.35–2.45 m)

Buzzards 4 to 5 ft (1.2–1.5 m)

Kites 2.6 to 6.4 ft (0.8–1.95 m)

Red-Backed Hawk
3.4 to 4.4 ft (1.05–1.35 m)

Falcons 2.2 to 4.1 ft (0.67–1.25 m)

Feet

Most birds of prey catch and kill their prey with their talons and tear away the meat with their bills. For this reason, birds' feet constitute one of the morphological characteristics of a species. The toes end in strong, sharp nails that the bird uses as pincers to catch its prey in flight. The osprey also has thorns on the soles of its feet, which help it to catch fish.

GRIFFON VULTURE
Its long toes do not have a good grasp.

FISHING EAGLE
Its toes have rough scales that look like thorns, which help it to catch fish.

GOSHAWK
It has calluses at the tips of its toes.

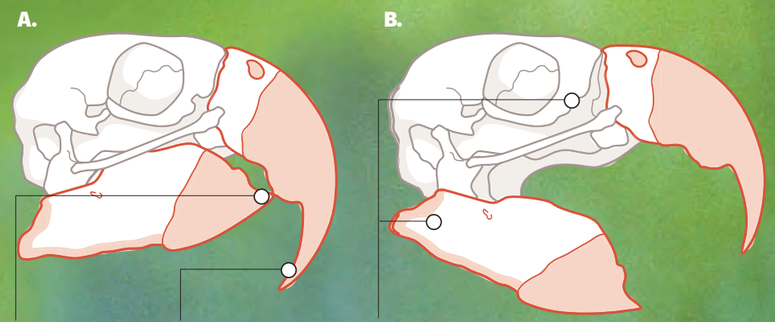
SPARROW HAWK
Its feet have tarsi and short, strong toes.

Talkative and Colorful

Parrots form a very attractive bird group with a great capacity for learning. This group comprises cockatoos, macaws, and parakeets. They share physical characteristics, such as a big head, a short neck, a strong hook-shaped bill, and climbing feet. They have plumage in many colors. Toucans and woodpeckers share with parrots the colors of their feathers and their type of feet. Toucans have a wider, thicker bill, but it is light. Woodpeckers are climbing birds with a strong, straight bill, a tail of stiff feathers, and a distinctive crest. They form numerous groups, and most nest in trees.

Eating, Climbing, and Chattering

Parrots use their bills to feed and to move about tree branches; they use their bills as an extension of their feet to give them support when they climb. Parrots also have a curved profile, a pointed tip on their upper mandible, and sharp edges on their lower one. These adaptations are practical when it comes to cutting and breaking fruits and seeds. The largest species like fruits with shells, such as walnuts, hazelnuts, and peanuts. The smaller ones prefer nectar and pollen, which they obtain with the help of brush-shaped bristles on their tongues. Their ability to imitate the human voice has made them very popular. However, they are far from being able to produce language. In reality, they are merely good imitators: they use their excellent memory to imitate sounds. They do this when they are hungry or when they detect the presence of unknown people.



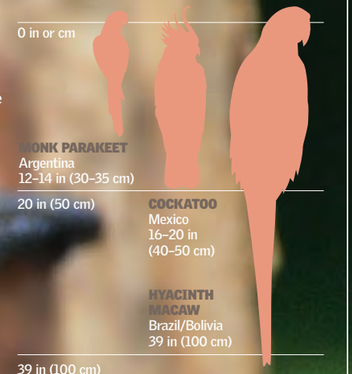
UPPER PART OF THE BILL
It is where the most pressure is exerted and fruits are torn open.

HOOK
Sharp projection used to open seeds

UPPER AND LOWER MANDIBLES
The hook-shaped bill is flexible; the mandibles are joined to the skull by hinges. At its base, the upper mandible has a fleshy protuberance called a cere.

WINGS
Usually they are short and rounded, suitable for flying among branches.

COMPARISON
American parrots vary in size, from the monk parakeet *(Myopsitta monachus)*, which is 12 inches (30 cm) tall, to the hyacinth macaw *(Anodorhynchus hyacinthinus)* from South America, which is 33 inches (1 m) tall.



The Feet

are referred to as zygodactyl. This means that two toes project forward and two project backward. Parrots appear to strut because their feet have a tibiotarsus that is shorter than that of other birds.

FEET LIKE HANDS
In some species, the left foot is longer. They use it to grab fruits and tear them with their bills.

WOODPECKERS
hollow out tree trunks with pecks in order to build a nest and to feed on insects that eat wood.

THE HABITAT OF WOODPECKERS

They live in the woods and can often be heard there. Their adaptations to arboreal life are demonstrated by their strong, thick bills and their stiff tails, which they use for support, together with their feet. They use their hearing to locate tree-boring insects; they then peck the wood incessantly until they find them.

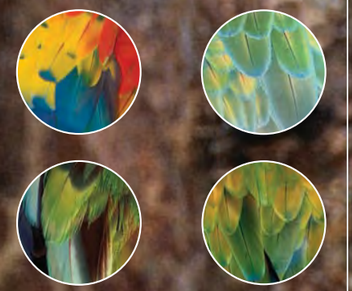
TOUCANS
Their big bills have serrated edges that suit their diet of fruit. They live in the South American jungles.

QUETZALS
They belong to the family Trogonidae. They have feet adapted to arboreal life. Males have brilliant plumage and long, attractive tails.

NOSTRILS
They are located at the base of the bill's upper portion.

HOOKED BILL

FEATHERS AND COLORS
They have tough and lustrous plumage. An abundance of green feathers helps them to hide among the leaves. In South America, the array of colors includes hues of blue, yellow, and red.

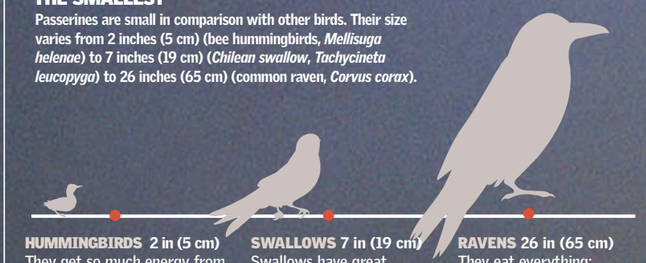


The Perchers Club

Passerines—or Passeriformes, the scientific name—form the widest and most diverse order of birds. What distinguishes them? Their feet are suited for perching and, therefore, for living among trees, although they can also stroll on the ground and through the brush. They inhabit terrestrial environments all over the world, from deserts to groves. Their complex sounds and songs originate from a very well-developed syrinx. Their chicks are nidicolous—that is, naked and blind at birth. In their youth, they are agile and vivacious, with very attractive, abundant, and colorful plumage.

THE SMALLEST

Passerines are small in comparison with other birds. Their size varies from 2 inches (5 cm) (bee hummingbirds, *Mellisuga helenae*) to 7 inches (19 cm) (*Chilean swallow, Tachycineta leucopyga*) to 26 inches (65 cm) (common raven, *Corvus corax*).



HUMMINGBIRDS 2 in (5 cm)
They get so much energy from nectar that they can double their body weight by eating. However, they use this energy up during their frantic flights.

SWALLOWS 7 in (19 cm)
Swallows have great agility and skill. These popular migratory birds have bodies suited for long trips.

RAVENS 26 in (65 cm)
They eat everything: fruits, insects, reptiles, small mammals, and birds. They are skillful robbers of all kinds of food.

PASSERIFORMES BIRDS

Passerines have been classified into 79 families, with more than 5,400 different species.

50%

THE PERCENTAGE OF BIRDS THAT ARE INCLUDED IN THE ORDER PASSERIFORMES

SINGER

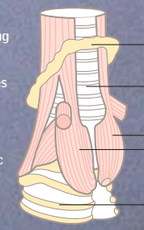
This blue-and-white swallow *(Notiochelidon cyanoleuca)* intones its pleasant and trilling chant while it flies or when it alights. Larks, goldfinches, canaries, and other passerines delight us with their trills and sounds.

HARD, SHORT BILL

The bill of a swallow is very short and tough. The swallow can use it to catch insects in flight.

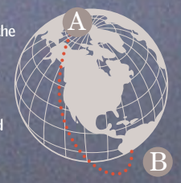
SYRINX

This sound-producing organ is located at the end of the trachea. The muscles in the syrinx move the bronchial walls, which, as the air passes through, produce the melodic sounds that characterize songbirds.



LIVING AT THE EXTREMES

They range from one hemisphere to the other. They raise their chicks in the north and fly to the south to spend winter there. They fly all the way to Tierra del Fuego. Their sense of direction is remarkable. They can find and reuse their nests after returning from a migration.



BARN SWALLOW
(*Hirundo rustica*)
Barn swallows spend most of their time traveling to temperate zones.

A In the summer, during the reproductive season, they live in the Northern Hemisphere on the American continent. In general, neotropical migratory birds are those that reproduce above the Tropic of Cancer.

B When winter arrives in the Northern Hemisphere, they perform a mass migration to the south, occupying the Caribbean and South America. The barn swallow travels 14,000 miles (22,000 km) during its migratory trip from the United States to southern Argentina.

PERCHING FOOT

Three toes project forward, and the well-developed hallux projects backward. This type of foot allows the bird to hold on tightly to branches.

Family Album

Four basic groups have been established to facilitate the study of families: passerines with wide bills; ovenbirds, whose plumage is dull and brown (ovenbirds are noted for the great care they take in building nests); lyrebirds, whose tails have two external feathers that are longer than the others; and songbirds, with their elaborate and pleasant singing. Songbirds form the most numerous and varied group; it includes swallows, goldfinches, canaries, vireos, and ravens.

LYREBIRDS

There are only two species of these Passeriformes, and they are found only in Australia. They are very melodic and are excellent imitators of other birds. They can even imitate the sound of inanimate objects, such as horses' hooves.

WIDE BILLS

They are native to Africa and Asia and inhabit tropical zones with dense vegetation. They eat insects and fruits. They produce nonvocal sounds with the flapping of their wings. They do this during courtship, and the sound can be heard 200 feet (60 m) away.

OVENBIRDS AND THEIR RELATIVES

Their nests are completely covered structures, similar to ovens. Other members of this family build nests with leaves and straw, weaving interesting baskets. Still others dig tunnels in the ground.

Humans and Birds

ROBIN CHICKS *(Erithacus rubecula)*
Although their natural habitats are humid groves, they usually seek shelter in cities, always close to water.

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Human beings have long taken an interest in studying these high-flying creatures. They have served as a source of food and have sometimes been used as indicators of the arrival of rain, storms, or the presence of common enemies, such as dangerous reptiles. Evidence of ancient peoples' veneration of birds can be found in documents, paintings, and reliefs. The Egyptians were the first to domesticate pigeons. Today several species brighten up homes with their colors and cooing. Other types of birds, such as sparrows and swallows, live with us in cities. The destruction of bird habitats, through the excessive exploitation of natural resources, is one of the main causes of bird extinctions. ●

Birds and Human Culture

Birds fly, sing, dance, and have showy plumage. Because of these qualities, they have fascinated human beings throughout history. Some species, such as eagles, have played an important role in world literature because of their aggressiveness and beauty. Some birds have also been assigned symbolic meanings: doves, which currently represent peace, are one example. Human beings have also been able to make use of birds. In the past, they were often used by sailors to find land, and in other cases they were trained to hunt.

Falconry

This practice originated in Asia, in the homeland of the nomadic Mongols—descendants of Genghis Khan—where, to this day, it is commonly used as a form of subsistence by part of the population. It consists of using birds of prey (mainly falcons) to hunt. Trained birds are typically carried, hooded, and perched on their masters' arms. When released, they fly at high altitudes looking for prey, and then dive toward the ground to hunt it. They carry the prey back to their masters, who reward them with food. The basic training process takes a little over a month and a half.

Rites and Beliefs

Birds have long enjoyed a prominent place in religion—first as totems and then as iconic representations of gods. Many religions have featured deities with the wings or heads of birds. Birds were also celestial messengers, and the future was interpreted through their flights. The crow was Apollo's messenger in ancient Greece; the Maya and Aztecs had Quetzalcóatl, their supreme god, who was named after the quetzal (a brightly colored Central American bird); and the Egyptians represented their fundamental god Horus with a falcon.

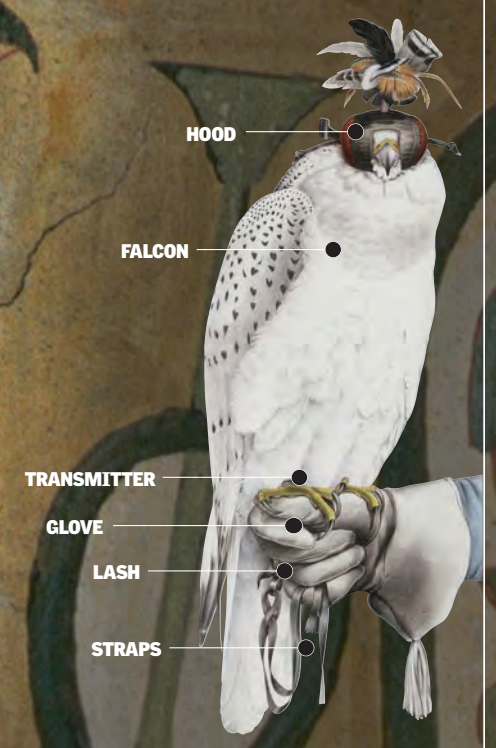
HORUS, THE FALCON, is an important god in Egyptian mythology. His eyes represent the sun and the moon, and together with Seth he watches over the boat of Ra, which carries the dead away on the Nile.

FENGHUANG was the messenger bird of Xi Wangmu, goddess of fertility and eternity in ancient China. A detail of a painting in the caves of Mogao, Dunhuang, China, is pictured above.

QUETZAL Pictured above is a detail of a Mayan ceramic piece featuring quetzals, Mesoamerican birds with long green tails, from which, according to myth, the god Quetzalcóatl took his clothing and name: "feathered serpent."

GARUDA FRESCO Pictured above is a winged deity, featured on a fragment of a mural from the Hindu temple of Garuda, in Ananta Samarkhom, Bangkok, Thailand.`

ELEMENTS
Birds and masters wear specific clothes. In addition to gloves, hoods, and straps, radio transmitters are now also used to locate the birds as they fly.

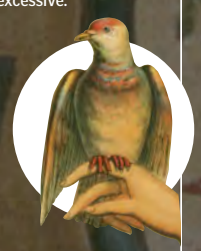


Bird Symbolism

Throughout history and across cultures, human beings have used birds to symbolize several concepts. The fascination that their flight creates was a source of inspiration for such interpretations. Today the strongest and most widespread association is that of the flight of birds with freedom. In distant times (and in not so distant times), however, birds have represented many other things, from fertility and happiness, with their spring songs, to deep mourning, in the case of crows and vultures. Wisdom has been associated with owls, and shrewdness with crows. According to a certain modern tale, storks are responsible for bringing babies, and eggs are the universal symbol of gestation.

PIGEON Sometimes their numbers in urban areas become excessive.

COMPETITOR BIRDS
When birds share a habitat with humans, they often compete for resources (light, water, space, and nutrients). This is the case with birds that feed on cultivated crops. Urban areas, which have buildings that offer good nesting sites, attract many birds. This fact can be commonly observed in squares and open spaces, where pigeons and sparrows form veritable flocks.



SPARROW The sparrow is one of the birds best adapted to the urban environment.

EAGLE
In Greek mythology, it was the symbol of Zeus. The Romans used it on their legions' banners. For many native North American cultures, it represented war, and it was the emblem of feudal lords and emperors. Today it is the national symbol of Mexico and the United States.

DOVE
Doves currently stand for peace, but in ancient Greece, Syria, and Phoenicia, they were used as oracles. In Mesopotamia and Babylon, they embodied fertility. For Christians, they symbolize the Holy Spirit and the Virgin Mary.

Dressing Up in Feathers

Almost all cultures have used bird feathers for decorative and ritualistic purposes. Their use as ornaments extended to North and South America, Africa, and the Western Pacific. North American indigenous peoples featured them on their war outfits, Hawaian kings wore them on their royal costumes, and the Mayans and Aztecs used them in works of art.

NORTH AMERICAN INDIGENOUS MAN wearing a war costume covered with feathers

How to Get to Know Birds

Ornithology (from the Greek *ornitho*, "bird," and *logos*, "science") is a branch of zoology that studies birds. Ornithologists and a great number of bird lovers, who enthusiastically want to know more about these creatures, carry out the task methodically and patiently. They observe, analyze, and register birds' sounds, colors, movements, and behavior in their natural environments. To undertake this fieldwork, they develop methods and techniques and use technological resources to track specimens and learn about what happens to them during given times of the year.

STUDIES
Many studies on anatomy, physiology, and genetics of different bird species are carried out in laboratories.

WORK CLOTHES
Although seemingly a small detail, clothes can be a hindrance. They should be comfortable and soft, appropriate for the weather, and of colors that blend into the environment.

BINOCULARS
They make it possible to see details in color and shape without disturbing the birds. Their usefulness depends on the power of their lenses.

CAMERA WITH ZOOM LENS
A camera with a powerful lens provides the opportunity to record details that simple cameras cannot.

TAPE RECORDER
Recording birds' noises and songs makes it possible to distinguish among birds. Experts can identify species by listening to their recordings.

Direct Observation

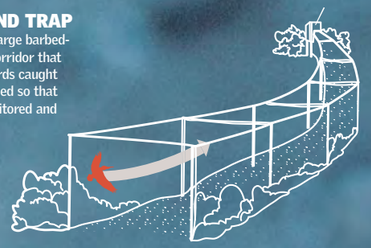
Observing in a bird's natural habitat provides much information. For the greatest success, bird-watchers typically place themselves in front of rocks or trees in order not to form a silhouette. An alternative technique is to create a hiding place, such as a hollow cardboard rock. In both cases, the watcher needs to be facing away from the sun and must be prepared to stay for a long time.

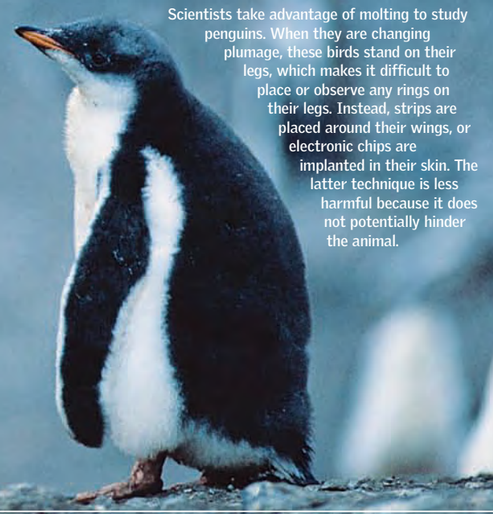
Catching Birds

MIST NET
These fine nets are usually placed over swamps or marshes, and they can catch small birds. Once the birds are identified with a ring or some other tag, they are set free.

CANNON NETS
These nets are "shot" over birds using cannons or rockets. They unroll and catch birds as they are eating or resting. They are used to catch large birds.

HELIGOLAND TRAP
It consists of a large barbed-wire funnel or corridor that ends in a box. Birds caught like this are tagged so that they can be monitored and studied later on.





Scientists take advantage of molting to study penguins. When they are changing plumage, these birds stand on their legs, which makes it difficult to place or observe any rings on their legs. Instead, strips are placed around their wings, or electronic chips are implanted in their skin. The latter technique is less harmful because it does not potentially hinder the animal.

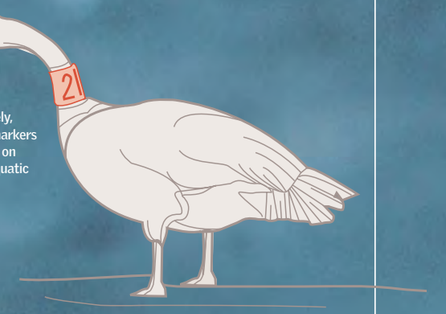
The Marking of Captured Birds

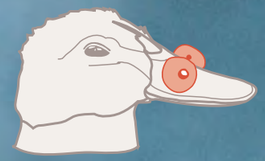
This technique provides data on migration, survival, and reproduction rates, among other data. The bird should not suffer adverse effects in its behavior, longevity, or social interactions. Under no circumstances should this procedure hurt a bird. To avoid hurting birds, rings are designed to be placed on them rapidly and easily, yet to stay in place until the research is completed.

RINGED
Numbered aluminum rings are used. When placing one on a bird, one should make sure that it slides and turns around the tibiotarsus to avoid hurting the bird or causing it to change its activity.

WING MARKERS
They are very visible and can be codified for individual identification. They stay on the bird for long periods of time and are normally used on birds of prey.

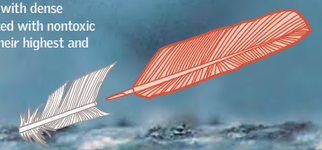
NECK MARKERS
When placed appropriately, necklaces are effective markers with few adverse effects on geese, swans, or other aquatic birds with long necks.





NASAL MARKERS
These are colored, numbered plastic disks placed on the bill. They are fastened to the nasal orifices of aquatic birds.

PAINTS AND DYES
Birds that visit environments with dense vegetation are normally marked with nontoxic colorings on the feathers of their highest and most visible body parts.



Among Us

The urban environment presents opportunities for birds. It offers advantages in finding food and shelter. People, young and old, give bread crumbs to these interested visitors. When birds come to cities, houses and parks offer them protection. They can find more options when it comes to building a nest. Seagulls and owls have changed their behavior by adapting to the city, and other species, such as some sparrows, are no longer able to survive without a human presence. However, not everything is an advantage. In the city, birds have to face dangers and obstacles that do not exist in their natural habitat: a utility wire or a car can be fatal.

Where to Find Them

In big cities, groups of birds can be found in different areas. Busy and noisy areas, such as squares, parks, and gardens, attract many species. Calm, deserted spaces, such as cemeteries or deserted buildings, are chosen by birds in search of peace. Other places where birds choose to eat and sleep include plots and landfills with lots of food, as well as nooks in high places, such as balconies, belfries, and roosts.

PLOTS AND CEMETERIES

Plants with seeds usually grow in these places, which are located far from urban centers. For this reason, magpies and nightingales favor them.

DAY/NIGHT

Artificial night lighting intensifies birds' activities. They organize their tasks according to street lighting.

URBAN CENTERS

With the arrival of cold weather, different bird species from the countryside and the mountains come to the city. In general, they stay until the beginning of spring. In the winter, more birds, such as chiffchaffs, great tits, and robins, can be observed in cities.

FALCONS
Diurnal birds of prey. They nest on the roofs of high buildings.

PIGEONS
spend a lot of time together. They are granivores but eat all kinds of food.

SWIFTS
are insectivores. They catch their prey in flight.

STORKS
build their nests on rooftops.

SEAGULLS
usually fight among themselves for the food they get from landfills.

LANDFILL

OWLS
Belfries or abandoned buildings are the homes or dormitories of these birds.

ABANDONED BUILDING

PARKS AND GARDENS

Royal peacocks and green peafowls share these places, where they can find the microhabitats of insects on which they feed. Parks and gardens may have ponds that are visited by other bird species as well. Few species nest in these places because these spaces offer little quiet.

BLACKBIRDS
were originally migratory, but as they adjusted to cities, they became nonmigratory.

SPARROWS
Small birds with a highly varied diet

GROVE

ROBINS
They get close only to find food. Their trills and plumage are attractive.

WAGTAILS
nest in holes or crannies, always near water.

The Urban Environment

This setting is characterized by environmental and climatic factors that are different from the natural ones. It has more varieties of plants, higher average temperatures, less wind, more rain, cloudier skies, and less solar radiation. Polluted air and soil are harmful factors for both humans and birds.

10%
RAIN
INCREASE

15%
WIND
INTENSITY DECREASE

1.5°
TEMPERATURE
INCREASE DOWNTOWN

FEEDER WITH FRUITS

DIET

Some species, which are veritable strategists, benefit from human activities. For example, seagulls can feed on garbage; great tits drink milk from containers by adroitly uncapping them; and some magpies have learned to tear cardboard containers to eat the eggs inside.

Population Control

Without enough predators and with an abundance of food, urban bird populations grow exponentially.

800,000
RAVENS, CROWS, AND RELATED BIRDS
LIVE IN MOSCOW.

160,000
PIGEONS
DESCEND ON THE SQUARES AND STREETS OF BARCELONA.

Bird Domesticators

The breeding of birds in captivity has great social and economic value. This activity is carried out all over the world on industrial poultry farms and family farms where birds are raised for consumption and sale. A great variety of domestic birds have been developed from species inhabiting natural environments. We use their flesh and eggs as food and their feathers in coats to protect us against the cold. We also use birds for communication and as colorful and melodic pets. They are so dependent on people that in some cases they cannot survive when they are freed.

CAGED
Canaries, native to the Canary Islands, have been selectively bred by humans for nearly four centuries.

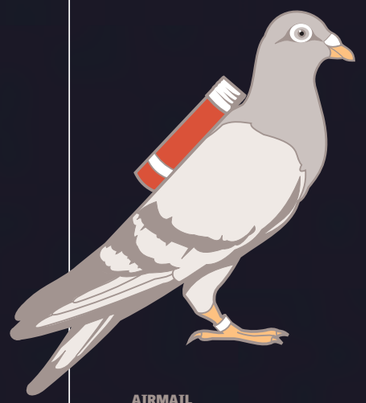
At Your Service

Domestic birds have been bred from the following orders: Galliformes (hens, quails, turkeys, and pheasants), Anseriformes (ducks and geese), Columbiformes (pigeons), Passeriformes (canaries), and Psittaciformes (parakeets and parrots). In poultry farming, they are divided according to their use: barnyard birds (Galliformes, Anseriformes, and Columbiformes) and companion birds or pets (Passeriformes and Psittaciformes). Commercial poultry farming of barnyard birds generates high revenues worldwide. Farmers can take advantage of the fact that birds are very active during the day, that they readily live in groups, and that they have a high reproductive rate due to polygamous behavior. Pets have commercial appeal, with their colorful plumage, ability to express themselves, and friendliness toward humans. These characteristics make them much-appreciated pets.

TURKEY
On the American continent, these birds were domesticated by the indigenous pre-Columbians from a wild Mexican species called *Meleagris gallopavo gallopavo.*

GOOSE
Contemporary domestic breeds descend from wild Asian and eastern European species. They are voracious, which makes fattening them easy.

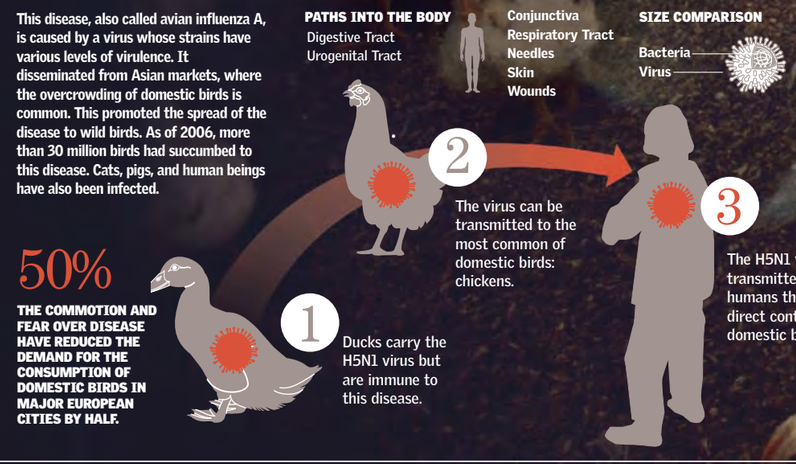
DUCK
These birds are an important source of food in Southeast Asia. In Central and South America, the consumption of ducks is less widespread.



AIRMAIL
For more than 1,700 years, human beings have used pigeons to send messages. Armies have used them as communication aids during wars. Pigeon keeping is the practice of breeding and preparing pigeons to become messengers, a task that makes the most of their agility and intelligence.

BIRD FLU

This disease, also called avian influenza A, is caused by a virus whose strains have various levels of virulence. It disseminated from Asian markets, where the overcrowding of domestic birds is common. This promoted the spread of the disease to wild birds. As of 2006, more than 30 million birds had succumbed to this disease. Cats, pigs, and human beings have also been infected.



50%
THE COMMOTION AND FEAR OVER DISEASE HAVE REDUCED THE DEMAND FOR THE CONSUMPTION OF DOMESTIC BIRDS IN MAJOR EUROPEAN CITIES BY HALF.

1 Ducks carry the H5N1 virus but are immune to this disease.

2 The virus can be transmitted to the most common of domestic birds: chickens.

3 The H5N1 virus is transmitted to humans through direct contact with domestic birds.

Farm Model

When compared to other farm animals, birds grow and reproduce easily. They need to have a place with appropriate temperature, humidity, and ventilation in order to yield the desired amount of meat or eggs. For this reason, it is necessary to maintain continuous environmental and sanitary control of the area in which they are bred. Ideally they should be able to walk, run, scratch the earth in search of food, and take sunbaths. Additionally, to protect them from predators and from inclement weather, it is important to shelter them in coops. This allows them to rest peacefully and sleep at night.

QUENCHING THIRST
Ten chickens drink from 0.5 to 0.8 gallon (2–3 l) of water a day. The farmer provides them with water in troughs, which are placed all over the henhouse.

MIXED DIET
Birds look for insects and plant shoots as they peck the soil. The breeder complements this diet with nutritionally balanced foods.

DOMESTICATION IN HISTORY

The domestication of birds is a very old activity, as shown by records from different cultures in different parts of the world. It was related to the adoption of a sedentary way of life by human populations.

5000 BC
India
There are records of domestic geese in India, beginning in 5000 BC.

2000 BC
Far East
Descendants of the royal duck *(Anas platyrhynchos)* were domesticated in this area of the Asian continent (what is now China).

1492
Mexico
The Spanish colonizers encountered turkeys domesticated by inhabitants of the New World.

Endangered Species

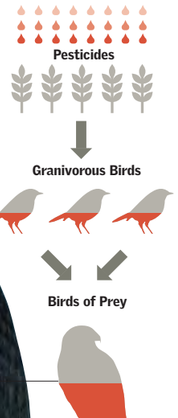
Since early civilization, people have affected the Earth's environment. The cutting of trees in rainforests and woodlands has destroyed many bird habitats, the loss of which is the leading cause of bird extinctions today. Also, the introduction of animals such as cats, dogs, and rats to new areas has created a threat for many bird species. Indirect poisoning with pesticides, the trafficking of exotic birds as pets, and the sale of feathers have done further damage to many species. Fortunately, all is not lost. The first step to conserving the world's avifauna is to learn about the extinction of birds and its magnitude.

The Most Important Causes

Birds are very sensitive to changes in their habitats, and this is the main cause of extinction (87 percent of species are affected by it). Excessive hunting is another of the greatest dangers, affecting 29 percent of the endangered species in the world. The introduction of foreign species is yet another major danger, jeopardizing 28 percent of species. In addition, the intervention of human beings through the destruction of habitats and the introduction of pollution combined with the occurrence of natural disasters harms more than 10 percent of species.

POISONING

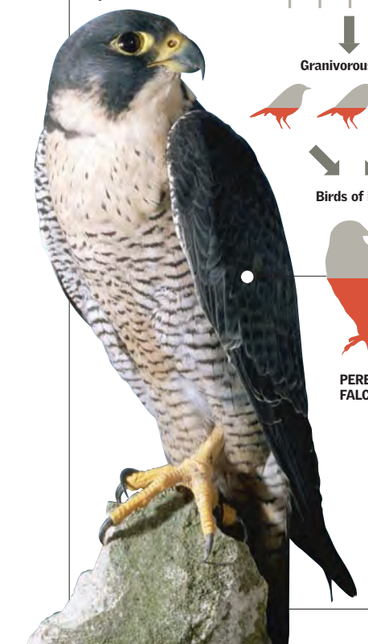
Most birds of prey are endangered by the excessive use of nonbiodegradable pesticides.



1 Pesticides are sprayed on crops to eliminate pests, and they stick to the seeds.

2 Small quantities of poison in seeds accumulate in larger amounts in birds and other granivorous animals.

3 Birds of prey eat the granivores. The increasing use of pesticides impacts hunting birds the most.



PEREGRINE FALCON

CALIFORNIA CONDOR
Gymnogyps californianus
Until 1978, there were 30 specimens in the wild. Bred in captivity, new specimens have been set free since 1993. Their adaptation is being studied.

HYACINTH MACAW
Anodorhynchus hyacinthinus
It is estimated that 1,000 to 9,000 specimens live in the Amazon.

MANGROVE FINCH
Camarhynchus heliobates
There are about 100 remaining species on the Galapagos Islands.

ROYAL CINCLODES
Cinclodes aricomae
live on humid mountain ranges, at altitudes between 11,500 and 15,000 feet (3,500–4,500 m). Their number is unknown.

SAVING THE PEREGRINE FALCON FROM EXTINCTION

1942 There were 350 couples of peregrine falcons in the United States.

1960 Peregrine falcons disappeared in the wild because of excessive use of pesticides (DDT and dieldrin).

1970 Falcons were bred in captivity at Cornell University, to be set free later.

1986 850 birds were set free in the southern United States.

BirdLife International
It monitors endangered species and develops conservation programs.

CLASSIFICATION OF RISK

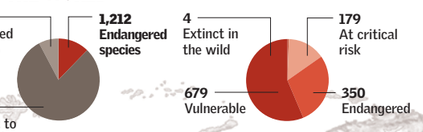
Extinct in the Wild Species surviving only in captivity

Critical Risk Extinction is imminent

Endangered Fast-decreasing population

Vulnerable High risk of extinction in the wild

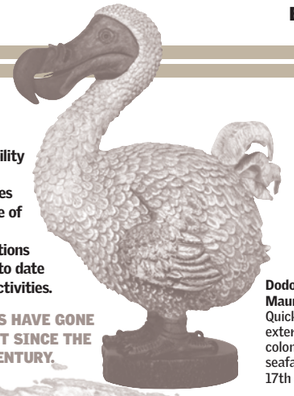
BIRDS OF THE WORLD



EXTINCT BIRDS

Although the responsibility of human beings is undeniable, many species became extinct because of natural phenomena. However, all the extinctions from the 18th century to date are related to human activities.

129 SPECIES HAVE GONE EXTINCT SINCE THE 18TH CENTURY.



Dodo from Mauritius
Quickly exterminated by colonizers and seafarers in the 17th century

INDIAN VULTURE
Gyps indicus
Its population has decreased significantly as a result of the veterinary use of diclofenac. The vulture eats the carrion of animals treated with this drug and becomes poisoned.

BENGAL VULTURE
Gyps bengalensis
From 1996 to date, its population has fallen by 95 percent, especially in India.

MALAYSIAN COCKATOO
Cacatua haematuropygia
It is estimated that there are between 1,000 and 4,000 individuals remaining. It was hunted indiscriminately.

YELLOW-CRESTED COCKATOO
Cacatua sulphurea
In three generations, its population fell by 80 percent because of hunting.

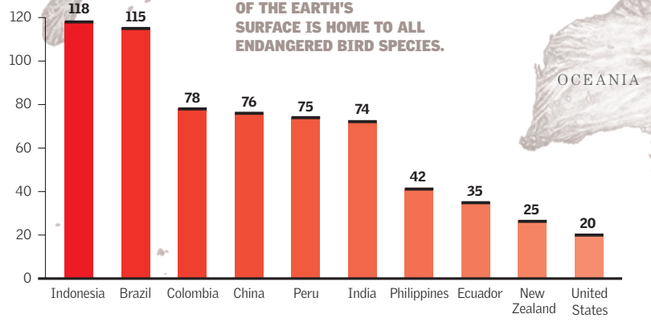
CAMPBELL ISLAND TEAL
Anas nesiotis
Only 50 individuals remain because of the introduction of mammals to the island.

LEGEND
● SHELTERS AND SANCTUARIES FOR ENDANGERED BIRDS

Alarming Data

Five percent of the planet's surface houses three fourths of endangered species. This area coincides with tropical regions where biodiversity is greater. For this reason, tropical countries top the list to the right. On some islands, the proportion of endangered birds is very high: in the Philippines and in New Zealand, it includes 35 to 42 percent of avian fauna.

20%
OF THE EARTH'S SURFACE IS HOME TO ALL ENDANGERED BIRD SPECIES.



Glossary

Adaptation

Change in the body of a bird or another animal that allows it to reproduce better in a given environment

Adaptive Radiation

Evolution of an initial species, adapted to a given way of life, into other species, each adapted to its own way of life

Aerodynamic

Having an appropriate shape to decrease resistance to the air. Birds' bodies are aerodynamic.

Alulae

Rigid feathers whose function is to decrease air turbulence during flight

Amino Acid

Molecule from which proteins are produced

Ancestor

Progenitor, more or less remote, that passes down a set of characteristics to its descendants

Angle of Attack

The change in position of a bird's wing to increase or decrease speed and altitude while hunting prey by air

Apterylae

Naked areas of the skin where feathers do not grow

Atrophy

Significant decrease in the size of an organ. The wings of nonflying birds have undergone atrophy during evolution.

Barbs

Thin, straight, parallel blades, perpendicular to the shaft. They resemble the leaves of a palm tree.

Bill

Hard cover of a bird's mandibles; also called the bill.

Biodiversity

Variety of species that live in a given natural or artificial environment

Biogeographic Regions

Geographic regions that biologists analyze to determine the distribution of animals and other living organisms, according to the geographic conditions of a place. Migratory birds usually travel through different biogeographic regions between winter and summer.

Biped

Aero-terrestrial animal that walks on its posterior limbs. Birds are bipeds.

Briny

Water sample or body of water containing between 0.08 and 4.25 ounces (0.5-30 g) of salt per gallon of aqueous solution

Bronchus

Each of the branches into which the trachea divides. The syrinx originates in the bronchi.

Calamus

The lower part of the vane that is wider, hollow, and, in general, naked. The feather is attached to the skin through the calamus.

Camouflage

A characteristic that enables the animal to blend into its environment. It allows the animal to go unnoticed in the presence of predators.

Carnivore

An animal that feeds on meat

Carrion

The remains of dead animals used as food by some birds or other animals. Vultures are scavengers (i.e., animals that feed on carrion).

Center of Gravity

Point at which the sum of all the gravitational forces that act on a body converge

Cere

Thin skin layer that covers the base of the bill

Chick

A baby bird that has just come out of the eggshell and that has not yet left the nest. Its diet and safety depend on its parents.

Chorion

One of the coverings that wraps the embryo of reptiles, birds, and mammals

Class

One of the many divisions scientists use to classify animals. Birds form a class of their own.

Climate

Average temperature, humidity, and pressure that determine the atmospheric conditions of a region and that are related to other geographic characteristics of that region

Cloaca

The widened and dilatable final portion of the intestine of a bird or other animal in which the urinogenital tubes converge

Courtship

Behavior patterns that males and females follow to try to attract partners

Coverts

Layers of contour feathers that provide a bird's body and wings with support and an aerodynamic surface

Crepuscular

Active at dawn or twilight, when there is little light

Crest

Extended or raised feathers located on the upper part of a bird's head

Crop

Membranous sac that communicates with a bird's esophagus, where food is softened

Dermal Papilla

Structure from which a feather develops. It is composed of epidermal and dermal cells.

Display

Behavior directed at attracting the attention of a partner. It can also be done to threaten or distract another animal.

Distribution

Place where a species is located. It includes the area the species occupies in different seasons.

Down Feather

A very thin and light feather, similar to silk, that birds have underneath their external plumage. Down feathers constitute the first plumage of chicks.

Ecosystem

Community of living beings whose vital processes are interrelated and develop according to the physical factors of the same environment

Egg

Large rounded shell, laid by a female bird, that contains a yolk and a white. If fertilized, the egg has a tiny embryo that will develop into a chick (the chick feeds itself on the yolk and white). When ready, the chick will break the eggshell.

Egg Tooth

Sharp calcium growth, in the shape of a tooth, that forms on the tip of a chick's bill during the embryonic phase. The chick uses the egg tooth to break its shell at birth.

Environment

The natural conditions, such as vegetation and land, that surround animals and influence their development and behavior

Epiphysis

Endocrine gland located below the corpus callosum in the brain. It produces a hormone that regulates sexual activity.

Evolution

Gradual process of change that a species undergoes to adjust to the environment

Extinct

No longer existing. Many bird species are now extinct (for example, ictiornites).

Feather

Each unit of the covering (plumage) of a bird. The feathers are composed of a hard substance called keratin. They have a long quill, to which two blades are joined. The blades—formed by a great number of barbs, uniformly distributed—give the feather its shape and color.

Fertilization

Union of the reproductive cells of a male and a female that will create a new individual

Field Mark

Natural distinct feature or artificial identification of an individual of a bird species that helps ornithologists distinguish it from other individuals of the same or other avian species

Fledgling

Very young bird that lives in the nest where it was raised

Fossils

Vestiges of ancient creatures of different types (vegetal or animal) on a stone substratum. Fossils can be found in the geologic strata of the Earth's surface.

Gastric Juice

Set of fluids produced by the stomach glands of birds and other animals

Gizzard

Muscular stomach of a bird. It is very robust, especially in granivores, and it is used to grind and soften the food by means of mechanical pressure. The food arrives at the gizzard mixed with digestive juices.

Gland

Type of structure that is present in most multicellular living beings. It produces substances that act either inside or outside a bird's body.

Gonad

Organ that makes male or female gametes. In birds, the testicles and ovaries are gonads.

Granivore

Bird that feeds on seeds or grains. Many birds are granivores (for example, parrots and toucans).

Gular Sac

Skin fragment in the shape of a sac that hangs from the lower mandible of certain birds (for example, pelicans)

Habitat

Native or natural environment of an animal or plant

Hatching

Cracking of the eggshell so that the bird cancome out

Histologic

Related to tissues and their study. When the anatomy of a bird is studied, the tissues that form the bird's organs are analyzed.

Hormones

Secretion of certain glands that circulates through the body. They excite, inhibit, or regulate the activities of organs or of systems of organs.

Horn

Made of horn or of a consistency similar to that of horn. The bill of birds is hornlike.

Hypophysis

Internal secretion organ located at the hollow of the skull's base (called silla turca). It is composed of two lobes: one anterior and glandular and the other posterior and nervous. The hormones produced by the hypophysis influence growth and sexual development, among other things.

Hypothalamus

Region of the encephalon located at the cerebral base, joined to the hypophysis by a nerve stem, in which important centers for vegetative life are found

Incubation

The act of keeping the eggs warm so that the embryos inside can grow and hatch. Usually the chick's parents use their own bodies to warm the eggs, but some birds use sand or decomposing plants to cover them.

Insectivore

Bird that eats insects as part of its diet

Instinct

Innate behavior that a bird or other animal develops and that is not learned. The offspring of ducks start to swim by instinct.

Invertebrate

Animal that lacks a spinal column. Worms, crabs, and jellyfish are examples.

Lethargy

Sleep through which a bird can reduce its cardiac rhythm and its body temperature to save energy, especially at night and during extended periods of cold

Malpighian Layer

Layer of epithelial cells that forms the bird's epidermis

Mangrove Swamp

Type of ecosystem often considered a type of biome. It is composed of trees that are very tolerant to salt. These trees are found in the intertidal zone of tropical coasts. Areas with mangrove swamps include estuaries and coastal zones.

Migration

The movement of birds from one region to another; it usually takes place in the spring and fall. It is also common among other species of animals.

Molt

Process through which birds lose old worn feathers, replacing them with new ones

Monogamous

Birds that mate with only one individual of the opposite sex. Many penguins have monogamous behavior.

Morphology

Study of the form of an object or structure. For instance, the morphology of the feet of birds is an area of study.

Nectar

Sweet and sugary secretions found in flowers that attract birds and other animals. Hummingbirds feed on nectar.

Nidicolous

A helpless chick that depends on its parents' care after birth

Nidifugous

A chick that can move and leave the nest as soon as it breaks its shell. In less than a day, such chicks can move agilely.

Nocturnal

Active at night. Many birds of prey, such as owls, specialize in nocturnal hunting.

Nutrient

Any substance obtained through diet that participates in the vital functions of a living being.

Omnivore

Bird that has a varied diet, including animal and vegetal foods

Pelagic

Birds that live in areas over open waters, away from the coast

Pellet (Bolus)

Small, hard mass that some birds regurgitate (vomit). It contains parts of the food that they could not digest, such as bones, fur, feathers, and teeth.

Pigment

Substance that colors the skin, feathers, or tissues of animals and plants

Piscivore

Birds living in continental or oceanic waters that feed on fish

Pollution

A consequence of human actions for natural environments. The emission of industrial gases into the atmosphere, for example, produces pollution.

Polygamy

Reproductive relationship between one animal of one sex and several animals of the other. When one male mates with several females, it is called polygyny. Only rarely do females have multiple male reproductive partners (polyandry).

Population

Set of individuals of the same species that live together in the same space at the same time

Predator

Animal that hunts other animals. Birds of prey hunt other birds, mammals, and vertebrates.

Prey

Animal hunted by another to serve as food for the latter. Animals that hunt prey are called predators.

Protein

Organic macromolecule that is part of living beings. By including proteins in their diet, birds get the necessary amino acids to build their own organs.

Protein Cord

Embryonic structure: each of the two filaments that sustain the yolk of the egg within the white

Proventriculus

The first portion of the stomach, or the true stomach, of a bird. The other portion of a bird's stomach is the gizzard.

Rectrices

Technical term used by ornithologists to describe a bird's tail feathers

Scale

Dermic or epidermic layer that totally or partially covers the feet of birds. They are reptilian vestiges.

Song

Sound or series of sounds produced by a bird to demarcate its territory or to find a mate. The songs of birds can be simple or elaborate, and some are very melodic.

Songbirds

Singing birds. Passerines include songbirds.

Species

Set of individuals that recognize themselves as belonging to the same reproductive unit

Sternum

Central chest bone. The sternum of flying birds has a large surface in which muscles are inserted.

Survival

A bird's ability to face the demands of its environment and of intra- and interspecies relationships

Swamp

Depression on the ground in which water is gathered, sometimes called a marsh. Its bottom is more or less boggy. It is the habitat of many wading birds.

Thermal

Hot air current that rises. Many birds make use of it to gain height effortlessly.

Theropods

Group to which carnivorous dinosaurs belong

Training

Teaching an animal new skills. Carrier pigeons are trained.

Tundra

Vast plains without trees in the Arctic regions of northern Asia, Europe, and North America

Uropygial Gland

Produces an oily secretion that birds, using their bills, spread on their feathers to make them impermeable

Vertebrate

Animals that have a spinal column, such as birds, fish, reptiles, amphibians, and mammals

Virus

Infectious agent that depends on a living being to reproduce. Avian flu is transmitted this way.

Vulnerable

Birds that are endangered in their natural habitats

Yolk

Yellow part of the egg. If the egg is fertilized, a small embryo grows that will use the yolk (and white) as food.

Young

Bird or any other animal at an early stage of life. Some young show color patterns that are very different from that of adults of the same species, which makes it difficult for predators to identify them.

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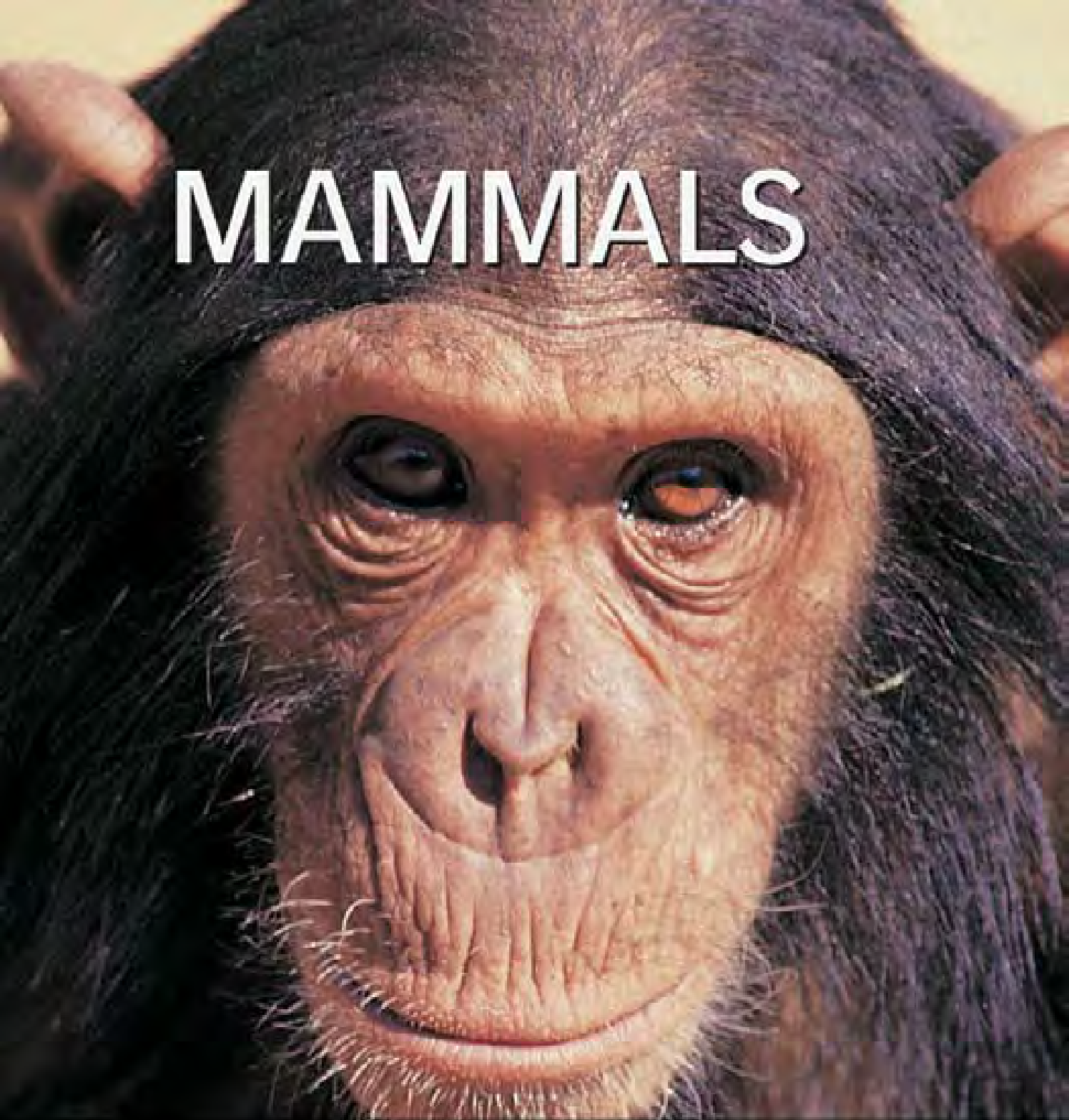

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MAMMALS

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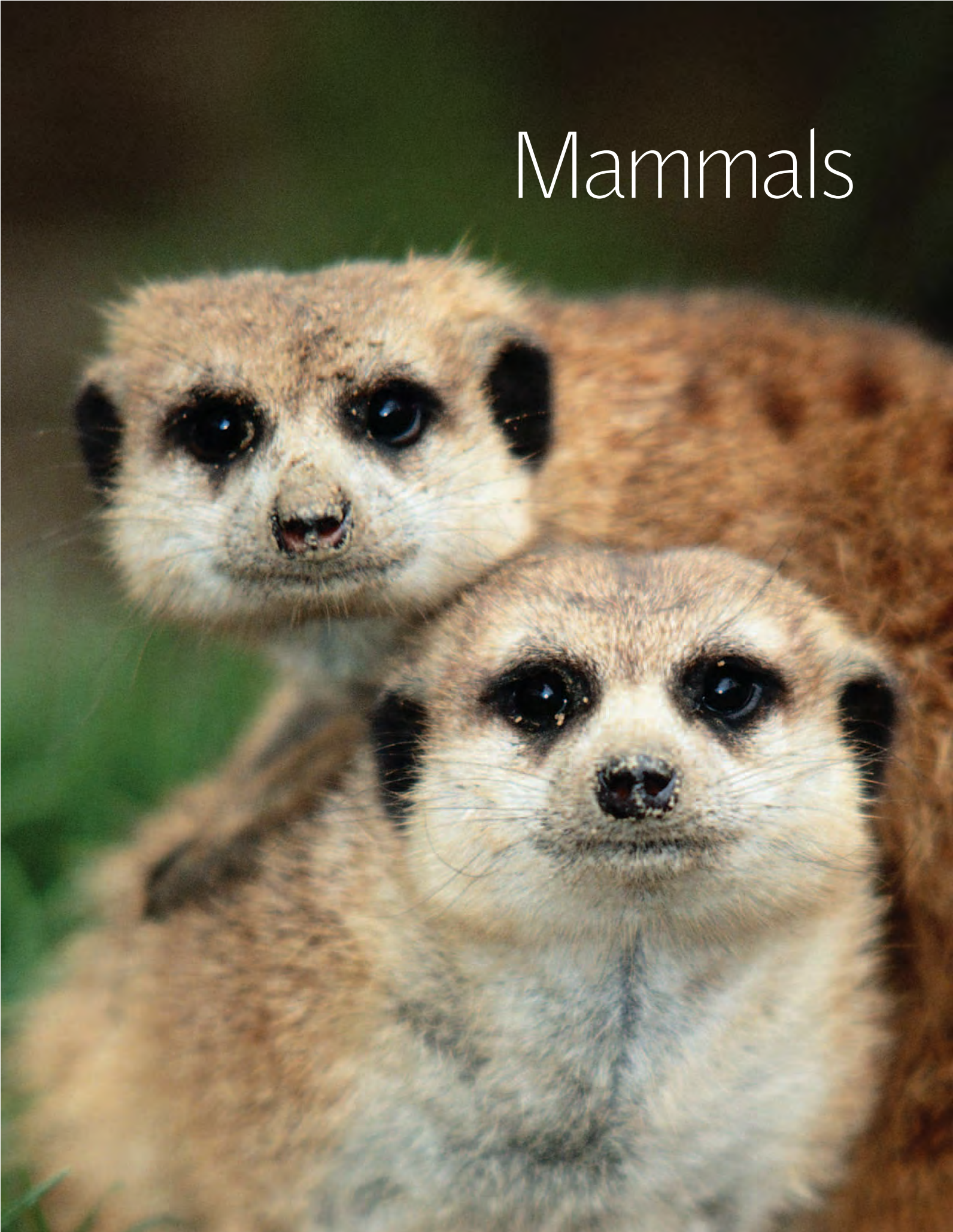

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WALES
Land of green meadows and gentle hills, Wales is famous the world over for the quality of its wool production.

Unique and Different

Mammals began to dominate the Earth about 65 million years ago. Without a doubt, modern humans are the most successful mammals—they occupy all the Earth's habitats! Their domestic coexistence with other species began barely 10,000 years BC, when human culture transitioned from a world of nomadic hunters and gatherers to a society based on agriculture. At that time, humans began to benefit from the meat and milk products of small mammals and to use large animals for labor. The first animals to be domesticated were sheep (about 9000 BC) in the Middle East. Pigs, cows, goats, and dogs followed. However, the great majority of mammal species continue, even today, to live in the wild.

There are 5,416 known mammal species distributed over different land and aquatic environments. Despite the characteristics that make them part of the same class, their diversity is such that the smallest of them, the shrew, may weigh only one tenth of an ounce (3 g), and the largest, the blue whale, can reach 160 tons. But their diversity is also evident in their adaptation to different environments. There are mammals that run and others that glide—some fly, and others jump, swim, or crawl. Most aquatic mammals have suppressed the development of hair or fur, replacing it with thick layers of fat. The rigors of low temperatures have made some animals—such as polar bears, dormice, and certain bats—exceptions to the vital law of homeothermy, as they spend the winter sunk in deep sleep to save energy.

Seals, dolphins, bats, and chimpanzees all have upper limbs with similar bones, but the environmental niche they occupy has made seals develop flippers, dolphins fins, bats wings, and chimpanzees arms. Thus from the polar tundra to the dense tropical jungle, through the deep oceans and high mountain lakes, the whole Earth has been populated by thousands of mammal species.

But this marvelous animal world has been disturbed by its most numerous species—humankind. Indiscriminate hunting, illegal trade, deforestation, urbanization, massive tourism, and pollution have left more than a thousand species (many of them mammals) endangered or vulnerable. However, science allows us to understand nature's many wonders, and it can help us respect the world's ecological balance. In this book, which includes dazzling photographs and illustrations, we invite you to discover many details of mammals' lives: their life cycles, their social lives, their special features, and their characteristics, from those of the greatest friend of them all, the dog, to the mysterious and solitary platypus.

Origin and Evolution

POLAR BEARS
Also called the white bear, they are without a doubt "Lords of the Arctic." Nevertheless, they are on the road to extinction.

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NAMES AND GROUPS 10-13
WHAT IS A MAMMAL? 14-15
CONSTANT HEAT 16-17

Polar bears are all-around athletes, as agile in the water as they are on land. Excellent swimmers, they move at a speed of 6 miles per hour (10 km/h) using a very rapid stroke. They can rest and even sleep in the water. Like all mammals, they have the ability to maintain a constant temperature. This allows them to tolerate the extreme cold of the Arctic ice. Here we will tell you many more things about the particular properties that distinguish mammals from the rest of the animals. Did you know that mammals appeared on Earth at almost the same time as dinosaurs? Since they were unable to compete with the large reptiles of the time, at first they were very small, similar to mice. Turn the page and you will discover many more things. ●

Millions of Years Ago . . .

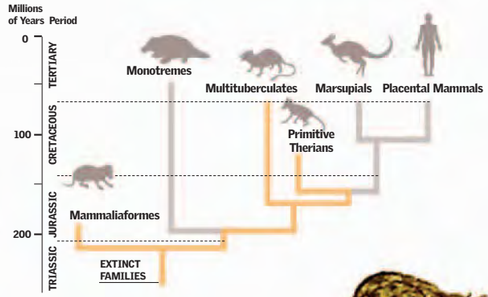
The origin of mammals lies in the Triassic Period a little more than 220 million years ago when, in the course of terrestrial evolution, new groups of animals appeared. Their history can be reconstructed in broad outline through the study of fossils. Among them is the morganucodon, an animal of which we have found numerous remains.

Morganucodon

Clade	Mammaliaformes
Group	Synapsids
Subgroup	Triconodonts
Family	Cynodont
Genus	***Morganucodon***

Weight
1 to 1.8 ounces (30-50 g)

6 inches (15 cm)

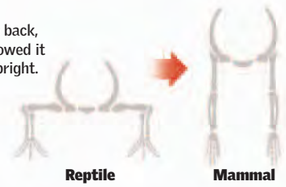


MONOTREMES
STEROPODON GALMANI

MARSUPIALS
DIPROTODON AUSTRALIS

PLACENTAL MAMMALS
ZALAMBDALESTES

POSTURE
The bones of the back, neck, and hip allowed it to stand more upright.



COAT
Although mammals are warm-blooded and can keep their body temperature constant, their fur coats protect them from the cold.

SCAPULA
connects the legs with the lumbar vertebrae.

LUMBAR VERTEBRAE
do not have ribs and withstand the body's twisting.

TAIL
is shorter than that of today's rodents and pointed.

ACETABULUM
connects to the lumbar vertebrae and pelvis.

TROCHANTER
is the part of the femur where muscles that assist locomotion are inserted.

PATELLA
is the knee, which connects the femur with the tibia and the fibula.

EPICONDYLE
articulates with the humerus and connects to the forelimbs.

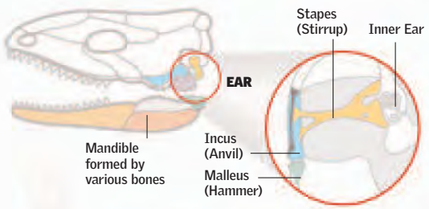
INTERIOR FOSSA
The transformation of the mandibular bones into those of the modern mammal is not yet complete.

HUMERUS
is bigger, allowing greater mobility of the forelimbs.

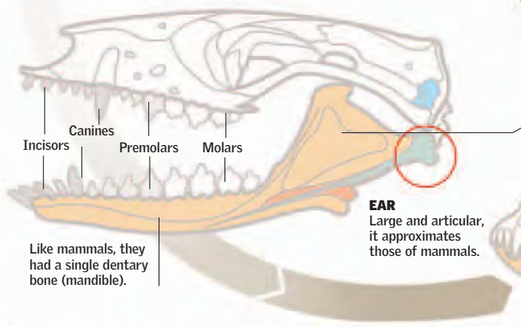
FROM REPTILE TO MAMMAL

KEY: Mandible; Squamosal; Angular; Subangular; Malleus (Hammer); Incus (Anvil); Stapes (Stirrup)

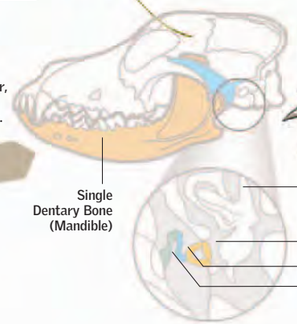
PRIMITIVE REPTILES
Resembled mammals in the bones of their back, neck, and hips, which allowed them to stand more upright. They replaced their teeth only once and had a much larger brain than today's reptiles.



MAMMALIAFORMES
Had differentiated dentition, with incisor, canine, and molar teeth. They also developed an extensive secondary palate, an`d the mandible was formed by the dentary bone. The posterior bones, which articulated with the cranium, had become smaller.

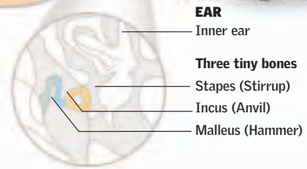


EAR
Large and articular, it approximates those of mammals.



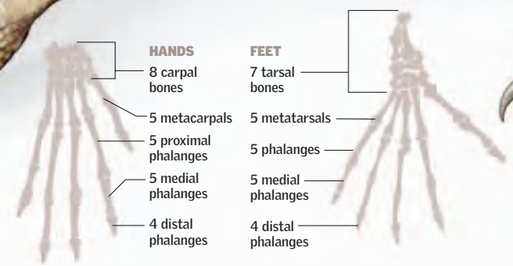
EAR
Inner ear

Three tiny bones
Stapes (Stirrup)
Incus (Anvil)
Malleus (Hammer)



MOLAR TEETH
Triangular in shape, the prior formation of incisors is reversed, and they increase to four.

MAMMALS
The cranium is larger, the mandible is formed by a single bone, the ear is articulated, and the teeth are of different shapes and sizes.



HANDS
8 carpal bones
5 metacarpals
5 proximal phalanges
5 medial phalanges
4 distal phalanges

FEET
7 tarsal bones
5 metatarsals
5 phalanges
5 medial phalanges
4 distal phalanges

Multituberculates

These Mesozoic mammals had features similar to those of living rodents. They had incisors in the mandible as well as in the cranium that grew continuously. There were both arboreal and digging multituberculates, and their fossil remains have been found on every continent except Australia and Antarctica.

Names and Groups

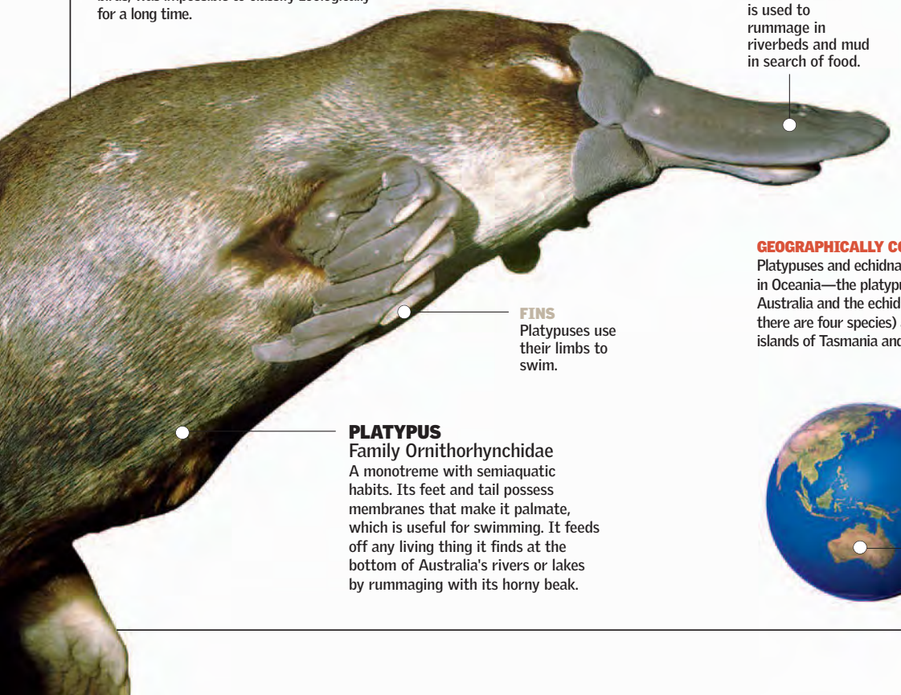
The mammals class is divided into two subclasses: Prototheria, which lay eggs (like other classes such as birds), and Theria. The Theria, in turn, are divided into two infraclasses—Metatheria (marsupials), which grow to viability within a marsupium, or pouch, and Eutheria (placental mammals), whose offspring are born completely developed and who today represent the great majority of living mammal species, including humans.

Prototheria
Order Monotremata

Oviparous mammals (Monotremata) are the oldest of all known groups. It is believed that their origin could be independent from that of other mammals and that they descend directly from the Synapsid reptiles of the Triassic Period (more than 200 million years ago).
Monotremes are the only mammals that lay eggs. However, the shape of their craniums, the presence of hair, and, of course, mammary glands show that they belong to the mammal group. The mammary glands lack nipples, so the young have to lick milk from a tuft of hair.
The only living representatives of this order are echidnas and the platypus. The platypus is a unique species that, because of its similarity to birds, was impossible to classify zoologically for a long time.

ECHIDNA
Family Tachyglossidae
Also known as the "spiny anteater" because it feeds on ants and termites that it catches with its tongue. Its skin has hair and spines.

CURRENTLY
4
SPECIES KNOWN



HORNY BEAK
is used to rummage in riverbeds and mud in search of food.

FINS
Platypuses use their limbs to swim.

PLATYPUS
Family Ornithorhynchidae
A monotreme with semiaquatic habits. Its feet and tail possess membranes that make it palmate, which is useful for swimming. It feeds off any living thing it finds at the bottom of Australia's rivers or lakes by rummaging with its horny beak.

GEOGRAPHICALLY CONFINED
Platypuses and echidnas are found only in Oceania—the platypus only on Australia and the echidna (of which there are four species) also on the islands of Tasmania and New Guinea.

AUSTRALIA

Theria
Infraclass Metatheria

The principal characteristic of metatherias, or marsupials, is the way they reproduce and develop. They have a very short gestation period compared to other mammals (the longest is that of the giant gray kangaroo, only 38 days), which means that their newborn are not very developed but have bare skin and eyes and ears that are still in the formative stage—although they have a sense of smell, a mouth, and digestive and respiratory systems adequate for survival. When they are born, they crawl across their mother's abdomen in search of her mammary glands. Kangaroo offspring climb to the edge of the mother's pouch (marsupium). They then crawl in and affix themselves to one of the mammary glands, from which they feed until they complete development and leave the pouch.

OVER
300
SPECIES EXIST.

TASMANIAN DEVIL
Family Dasyuridae
The largest of the carnivorous marsupials became extinct in Australia 600 years ago, but it survives on the island of Tasmania. It is a predator the size of a small dog.

AUSTRALIA

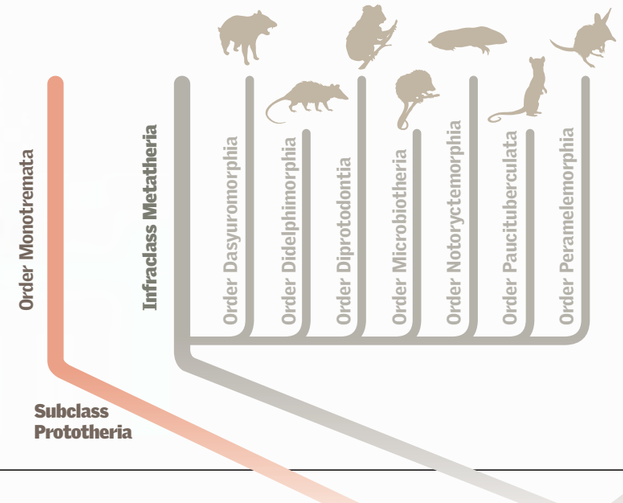
SOUTH AMERICA

ALMOST PATRIMONY
Unlike the rest of the world, almost no placental mammals live in Australia and its neighboring islands. The island continent possesses 83 percent of the unique (endemic) species of mammals.

OPOSSUMS
Family Didelphidae
They spend most of their lives perched in trees and are very timid.

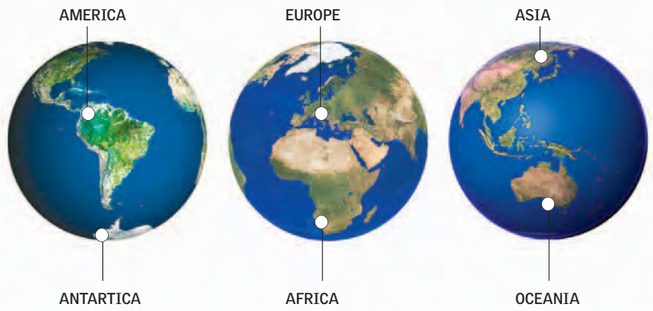
Mammals Colonizing the World

The first fossils of marsupials and placental mammals were found in rocks dating from the late Jurassic and the earliest part of the Cretaceous periods. At that time, America, Africa, and Australia were united in a single continent (Gondwana) and were beginning to separate. But the placental mammals evolved further, and at the beginning of the Eocene Period (56 million years ago), opossums were the only representatives in America of marsupials, which otherwise prospered only in Australia's particular climate and geographic isolation.



Infraclass Eutheria

Commonly called placental mammals, they are the typical mammals. They probably began diversifying during the Cretaceous Period (65-150 million years ago) from a different line of the metatherians. They are characterized by the fact that their embryos are implanted in the uterine cavity and develop an outer layer of cells in close union with the maternal body, the placenta. They receive nutrients directly from the placenta during their development until they are born with their vital organs (except for those responsible for reproduction) fully formed.

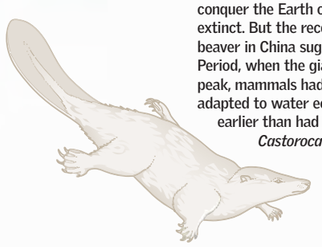


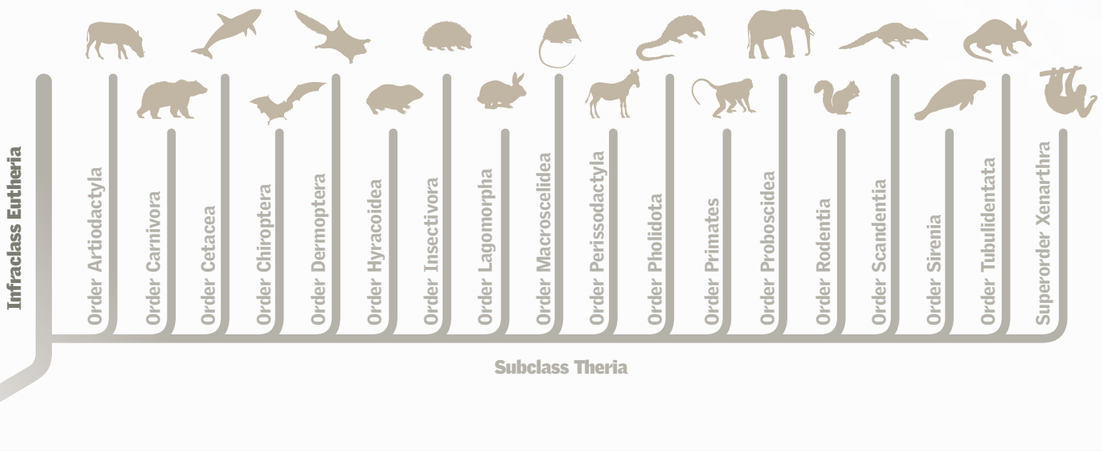
THROUGHOUT THE WORLD
The eutherians, or placental mammals, are the most important group of mammals because of the number of living species they represent. Their geographic distribution covers almost the entire planet, including on and beneath bodies of water and polar areas. These animals cover a wide range of ecosystems and forms of life and make up 19 orders of viviparous placental mammals.

RACCOON
Order Carnivora
Live in forests near rivers. These carnivorous hunters and climbers live in North America.

Jurassic Beaver

Scientists thought that mammals were able to conquer the Earth only after dinosaurs became extinct. But the recent find of a fossil of this beaver in China suggested that, by the Jurassic Period, when the giant reptiles were at their peak, mammals had already diversified and adapted to water ecosystems 100 million years earlier than had been believed. The *Castorocauda lufrasimilis* lived 140 million years ago.





GIRAFFE
Order Artyodactilae
These are the tallest of living land animals—they can be over 18 feet tall (5.5 m). They are herbivores. Their blood pressure is almost twice that of other large mammals, and their tongues are over 18 inches (0.5 m) long. They live in Africa.

NECK
allows them to reach the highest leaves.

SEALS
Order Carnivora
Along with elephant seals, they make up the Pinnipedia suborder. They move very clumsily on land, but they are very good swimmers. They feed on fish and crustaceans and prefer to inhabit marine waters near the poles, although they reproduce on dry land.

SKIN
A fur coat and subcutaneous fat protect the animal from extreme cold.

THERE ARE OVER
4,000
SPECIES OF EUTHERIANS.

MANDRILL
Order Primates
Weighing up to 120 pounds (55 kg), these are the largest monkeys in the world. The males are much larger than the females, and they have a brilliantly colored face, with deep grooves running down both sides of their snout. Mandrills live in Africa's tropical zones. They are omnivores, eating anything from grasses to small mammals.

What Is a Mammal?

Mammals share a series of characteristics that distinguish their class: a body covered by hair, the birth of live young, and the feeding of newborns on milk produced by the females' mammary glands. All breathe through lungs, and all possess a closed, double circulatory system and the most developed nervous systems in the animal kingdom. The ability to maintain a constant body temperature has allowed them to spread out and conquer every corner of the Earth, from the coldest climates to hot deserts and from the mountains to oceans.

A Body for Every Environment

Skin covered with hair and sweat glands helps create and maintain a constant body temperature. At the same time, with eyes placed on each side of the head (monocular vision, with the sole exception of the primates, which have binocular vision), they are afforded important angles of sight. Limbs are either of the foot or chiridium type, with slight variations depending on the part of the foot used for walking. In aquatic mammals, the limbs have evolved into fins; in bats, into wings. Hunters have powerful claws, and unguligrades (such as horses) have strong hooves that support the whole body when running.

BOTTLENOSE DOLPHIN
Tursiops truncatus

Hair

Body hair is unique to mammals and absent in other classes of animals. Sirenians, with little hair, and cetaceans are exceptions; in both cases, the absence of hair is a result of the mammal's adaptation to an aquatic environment.

Dentition

The majority of mammals change dentition in their passage to adulthood. Teeth are specialized for each function: molars for chewing, canines for tearing, and incisors for gnawing. In rodents such as chipmunks, the teeth are renewed by continuous growth.

CHIPMUNK
Family Sciuridae

5,416
THE NUMBER OF MAMMAL SPECIES ESTIMATED TO EXIST ON EARTH

Close Relatives

Humans belong to the primate group. Hominids (orangutans, gorillas, and chimpanzees) are the largest of these, weighing between 105 and 595 pounds (48-270 kg). In general, males are larger than females, with robust bodies and well-developed arms. Their vertical carriage differentiates their skeletons from those of other primates. Gorillas inhabit only the equatorial jungles of western Africa. They support themselves on their forelimbs while walking. Normally their height varies between 4 and 6 feet (1.2-1.8 m), but, if they raise their forelimbs and stand erect, they can be over 6.5 feet tall (2 m).

CRANIUM
Relatively large compared to the size of the body. And the brain is more developed and more complex than that of any other animal.

ALWAYS 98º F (37º C)
The ability to maintain a constant body temperature is not a characteristic unique to mammals; birds also have that ability.

AN EAR OF BONES
The tiny bones of the ear form a system for sensing and transmitting sound.

LOWER JAW
Formed by a single bone, called the dentary, and teeth specialized for each function. The entire cranium has a very simplified bone structure.

MAMMARY GLANDS
Secrete the milk with which the females feed their young during their first months of life. These glands give the class its name.

A THICK SKIN
Formed by an outer layer (epidermis), another deeper layer (dermis), and a fatty substratum that contributes to homeothermy.

GORILLA
Gorilla gorilla

Homeothermy

The ability to keep body temperature relatively constant, independent of the ambient temperature. Hibernating species are the exception; they must lower their body temperature to enter into this state of reduced metabolic activity. Contrary to popular belief, bears do not truly hibernate but rather enter into a period of deep sleep during winter.

GRIZZLY BEAR (BROWN BEAR)
Ursus arctos

Limbs

Mammals have four limbs that are adapted for moving about on land. Their forelimbs have certain other abilities (swimming, manipulation, attack and defense, protection). The exceptions are the cetaceans, so adapted to marine life that they only have two fingerless limbs, and seals (Phocidae).

ELEPHANT SEALS
Family Phocidae

Take Habitat into Account

Between every mammal and its natural habitat there is a relationship that exists and is expressed in the animal's physical characteristics. Just as the flippers of the elephant seal are used to swim and hunt fish, mimicry and running are vital for deer. Physiology is a special instrument of adaptation to the environment, as in the case of the camel.

AN UNCOMMON PRIMATE

Humans have adapted to almost all habitats through their ability to modify certain elements of their habitat to their advantage. They often create tools to help them adapt to their environment. In this way, they do not need to rely on natural evolution alone.

Constant Heat

Mammals are homeothermic—which means they are capable of maintaining a stable internal body temperature despite environmental conditions. This ability has allowed them to establish themselves in every region of the planet. Homeostasis is achieved by a series of processes that tend to keep water levels and concentrations of minerals and glucose in the blood in equilibrium as well as prevent an accumulation of waste products—among other things.

A Perfect System

Polar bears, like all mammals, keep their internal temperature constant. These bears tolerate the extreme cold of the Arctic ice because they have developed a sophisticated system to increase their ability to isolate and capture sunlight. Their transparent hair receives a large part of it and therefore appears to be white. The hair transmits this light inward, where there is a thick layer of black skin, an efficient solar collector. Their fur is made up of hollow hairs, approximately 6 inches (15 cm) long, which insulate the bear in low temperatures and keep the skin from getting wet when in the water.

SHELTERED CUBS
The cubs are born in winter, and the skin of the mother generates heat that protects the cubs from the extreme cold.

Migration

WHEN SPRING BEGINS, THESE BEARS TRAVEL SOUTH, ESCAPING THE BREAKUP OF THE ARCTIC ICE.

Metabolism

The layer of fat is between 4 and 6 inches (10-15 cm) thick and provides not only thermal insulation but also an energy reserve. When the temperature reaches critical levels—at the Pole it can drop to between -60° and -75° F (-50° to -60° C)—the animal's metabolism increases and begins to rapidly burn energy from fat and food. In this way, the polar bear maintains its body temperature.

UNDER THE ICE
Females dig a tunnel in the spring; when they become pregnant, they hibernate without eating and can lose 45 percent of their weight.

SECONDARY ACCESS TUNNEL

CHAMBER OR REFUGE

MAIN ACCESS TUNNEL

ENTRANCE

RESPIRATORY PATHWAYS
The bears have membranes in their snouts that warm and humidify the air before it reaches the lungs.

HAIR
An impermeable, translucent surface

Hollow chamber with air

LAYERS

GUARD HAIRS
Outer

UNDERFUR
Inner

FAT
4-6 inches (10-15 cm) thick

PRINCIPAL FAT RESERVES
Thighs, haunches, and abdomen

Curling Up

Many cold-climate mammals curl up into balls, covering their extremities and bending their tails over their bodies as a kind of blanket. In this way, the surface area subjected to heat loss will be minimal. Hot-climate animals stretch out their bodies to dissipate heat.

over
6 miles (10 km)
PER HOUR IS THE AVERAGE SPEED AT WHICH POLAR BEARS SWIM.

Great Swimmers

Polar bears swim with ease in open waters and reach a speed of 6 miles an hour (10 km/h). They propel themselves with their great front paws and use their back feet as rudders. The bear's hair is hollow and filled with air, which helps with buoyancy. When the bear dives, its eyes remain open.

POLAR BEAR
Ursus maritimus

SLOW AND STEADY SWIMMING

HYDRODYNAMIC ANATOMY

Hind Legs function as a rudder.

Forelimbs function as a motor.

AND FINALLY . . . THE FLOATING SLAB
When they tire of swimming, they rest, floating. They manage to cross distances of over 37 miles (60 km) in this manner.

TO GET OUT: ANTISLIP PALMS
Their palms have surfaces with small papillae that create friction with ice, keeping them from slipping.

What They Are Like

BENGAL TIGER
Panthera tigris tigris is the largest member of the feline family, easily recognized by its orange fur with black stripes and white spots.

GRACE AND MOVEMENT 20-21
EXTREMITIES 22-23
WHAT DOESN'T RUN, FLIES 24-25
LOOKS THAT KILL 26-27
DEVELOPED SENSES 28-29
SOFT CONTACT 30-31

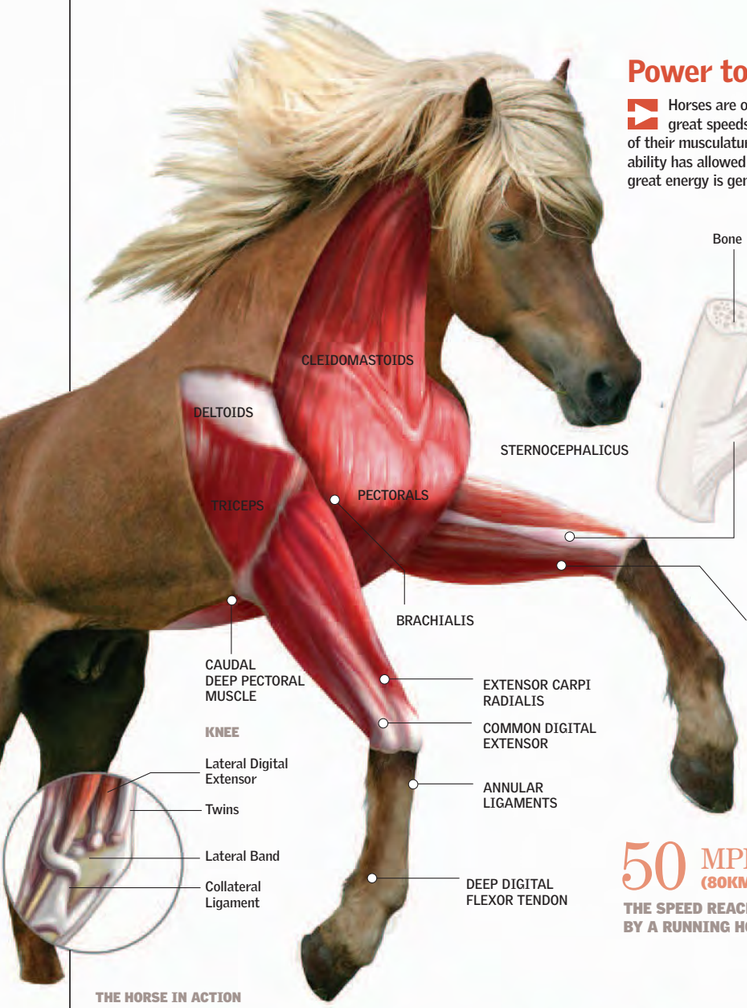
All mammals have stereoscopic vision, which gives them depth perception. Moreover, in the case of hunters such as tigers, their night vision is six times keener than that of humans. There are many species that have a very keen sense of smell, and the sense of taste is closely linked to that of smell. Hair, too, performs various functions in these animals' lives—conserving body heat, providing protection, and serving as camouflage. Those that have almost no hair and live in environments where the temperature is very low, such as whales, have developed a layer of fat under their skins. ●

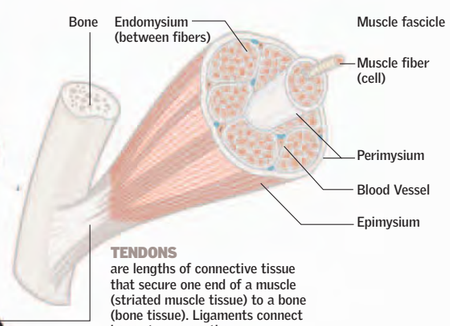
Grace and Movement

Horses, one of the odd-toed, hoofed, ungulate mammals, are considered symbols of grace and freedom. They have great vigor and can run swiftly because their spine bends very little, preventing unnecessary expenditure of energy during the rising and falling of their body mass. They are equipped with strong, light, and flexible bones, and their muscles work by contraction, arranged in pairs or groups that pull in opposing directions.

Power to Run

Horses are one of the most powerful mammals and achieve great speeds relative to their body mass. The natural purpose of their musculature is to allow them to flee their enemies. This ability has allowed the species to survive for millions of years. Their great energy is generated by contracting muscles.





TENDONS are lengths of connective tissue that secure one end of a muscle (striated muscle tissue) to a bone (bone tissue). Ligaments connect bones to one another.

50 MPH (80KMH)
THE SPEED REACHED BY A RUNNING HORSE

THE HORSE IN ACTION

Skeleton

BUCCAL CAVITY

14 TEETH in each maxillary bone, including:

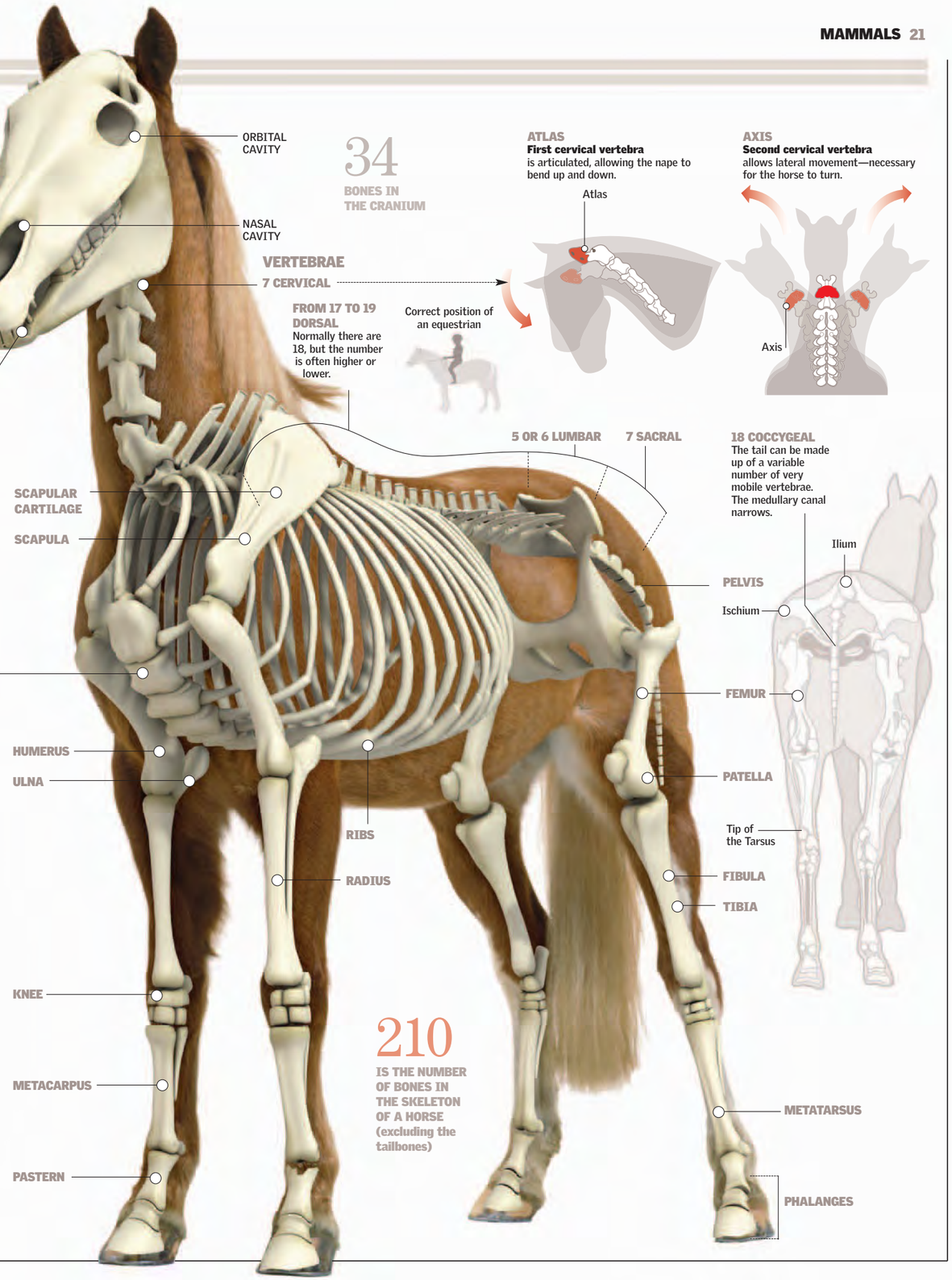
3 molars
3 premolars
6 incisors
2 canines

STERNUM is the bone that joins the ribs in the front of the chest, forming the thoracic cage and providing visceral support.

34 BONES IN THE CRANIUM

ATLAS
First cervical vertebra
is articulated, allowing the nape to bend up and down.

AXIS
Second cervical vertebra
allows lateral movement—necessary for the horse to turn.



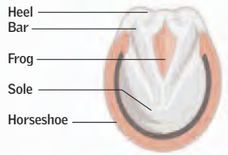
210 IS THE NUMBER OF BONES IN THE SKELETON OF A HORSE (excluding the tailbones)

GALLOPING LEGS

The hind legs generate the impetus and the leap, and the front legs bear the weight upon landing. To save energy, the spine hardly arches when running. In felines, however, which are lighter, it does.

EQUINE FOOT

HOOF Because they have this kind of "nail," horses are called ungulates, as are tapirs and rhinoceroses.

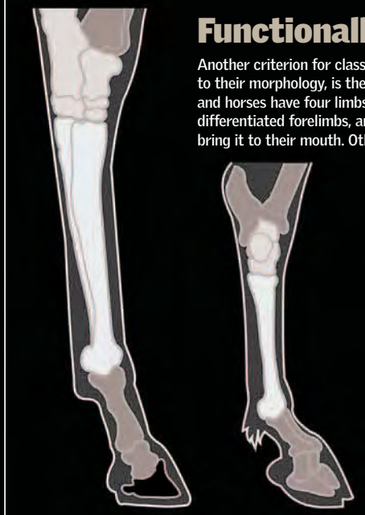


Extremities

Mammals' extremities are basically either of the foot or chiridium type but modified according to the way in which each species moves about. Thus, for example, they become fins for swimming in aquatic mammals and membranous wings in bats. In land mammals, these variations depend on the way the animal bears its weight in walking: those that use the whole foot are called plantigrades; those that place their weight on their digits, digitigrades; and those that only touch the ground with the tips of their phalanges, ungulates.

Functionally Adapted

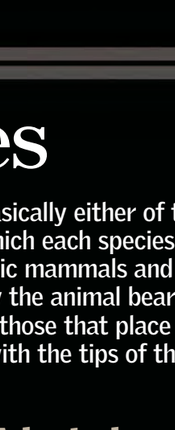
Another criterion for classifying mammals by their legs, in addition to their morphology, is the function the legs perform. Cats, dogs, and horses have four limbs for locomotion. Primates have differentiated forelimbs, and they also use legs to capture food or bring it to their mouth. Others use legs to swim or fly.



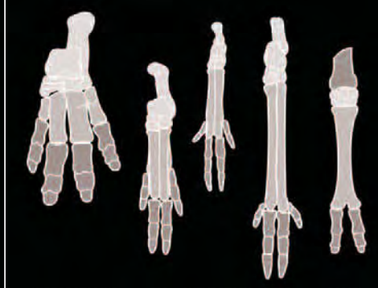
KEY
- Tibia/Fibula
- Tarsi
- Metatarsi
- Phalanges

UNGULIGRADE I
HORSES
If you observe their footprints, you will see that only their hooves leave marks. Horses' hooves are made up of only one toe.

UNGULIGRADE II
GOATS
The majority of ungulates, such as goats, have an even number of toes. They are called artiodactyls as opposed to perissodactyls, which have an odd number of toes.



LYING FOOTPRINTS
Other species of unguligrades (or simply ungulates) can have more toes that make up their hooves, but they do not place weight on more than two of them.



HIPPOPOTAMUS PIG CHEVROTAIN DEER CAMEL

DIGITIGRADE
DOG
These mammals place the full surface of their toes (or some of them) on the ground when walking. They usually leave the mark of their front toes and a small part of the forefoot as a footprint. Dogs and cats are the best-known examples.

5 toes

THE NORMAL NUMBER FOR MAMMALS: RUNNING SPECIES HAVE FEWER.

PLANTIGRADE
HUMAN
Primates, and of course humans, bear their weight on their toes and much of the sole of the foot when walking, particularly on the metatarsus. Rats, weasels, bears, rabbits, skunks, raccoons, mice, and hedgehogs are also plantigrades.

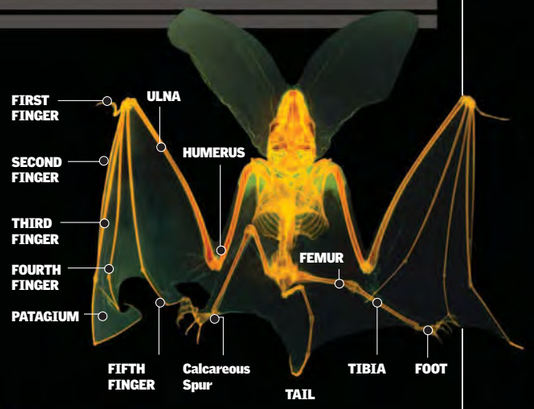
WALK OR CLIMB
There is a fundamental difference between the human foot and that of a monkey. The monkey has a long, prehensile digit in its foot similar to that in its hand. Monkeys use their feet to grab branches as they move through the trees.

Chimpanzee Human

LEFT FOOT OF CHIMPANZEE
Pan troglodytes
Life-size photo

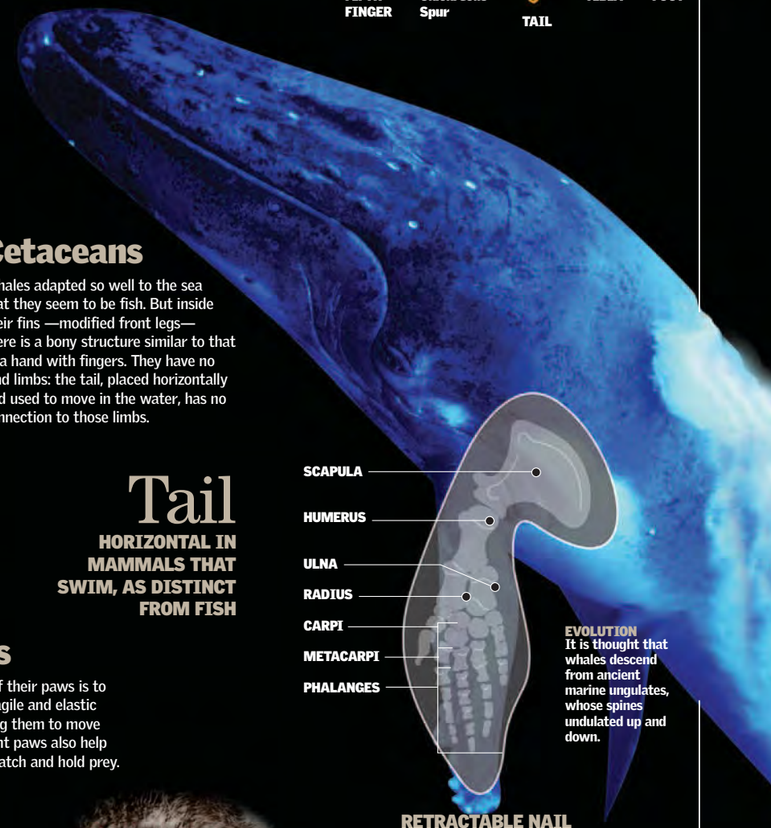
Chiroptera

From the Greek, meaning "winged hand," this is how bats are designated because their forelimbs are modified, the fingers thinning and lengthening to be able to support a membrane that functions as a wing. The hind limbs did not change similarly: they have claws.



Cetaceans

Whales adapted so well to the sea that they seem to be fish. But inside their fins —modified front legs— there is a bony structure similar to that of a hand with fingers. They have no hind limbs: the tail, placed horizontally and used to move in the water, has no connection to those limbs.



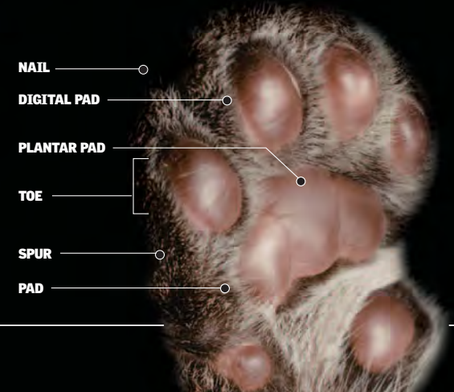
Tail

HORIZONTAL IN MAMMALS THAT SWIM, AS DISTINCT FROM FISH

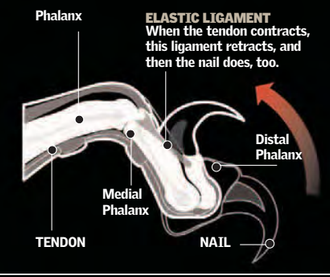
EVOLUTION
It is thought that whales descend from ancient marine ungulates, whose spines undulated up and down.

Felines

The function of their paws is to support their agile and elastic bodies, allowing them to move about. The front paws also help in hunting to catch and hold prey.



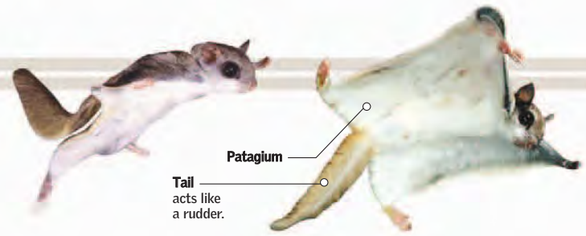
RETRACTABLE NAIL



What Doesn't Run, Flies

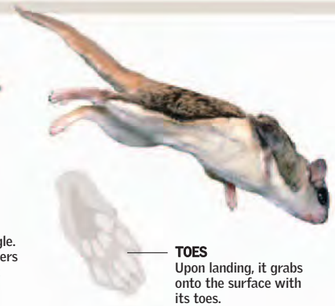
They are meteors of flesh, bone, and hot blood. Cheetahs are the fastest of the land animals and unique members of the Felidae family, which hunt using their keen vision and great speed. They can reach over 70 miles per hour (115 km/h) in short runs and reach 45 miles per hour (72 km/h) in an average of only 2 seconds. They can get above 60 miles per hour (100 km/h), but they can sustain that speed for only a few seconds. They look like leopards, although their physical characteristics are different: they are longer and thinner, and their heads are smaller and rounded.

TAKEOFF
From the top of a tree, it jumps toward another shorter tree.



IN THE AIR
The flying squirrel does not actually fly—it glides. Between its front and back limbs is a membrane of skin that, like a delta wing, stretches out the moment the animal jumps and stretches its legs. Thanks to that it can glide from the top of one tree to the trunk of another.

LANDING
While gliding, the squirrel can change its landing angle. Just before landing, it lowers its tail and raises its front legs, using the membrane like an air brake. It lands very gently on all four paws.



TOES
Upon landing, it grabs onto the surface with its toes.

Siberian Flying Squirrel

Flying squirrels (*Pteromys volans*) belong to the same rodent family as common squirrels, to which they are similar in both appearance and way of life. They live in the mixed forests of northern Europe, across Siberia, and into East Asia.

Cheetahs

Whereas tigers prefer to lie in wait for prey and then jump on it, the cheetah uses explosive speed of over 60 miles per hour (100 km/h) to run its prey down.

1 START
The cheetah begins running by lengthening its stride and extending its four legs.

2 SPINAL CONTRACTION
Then it gathers its legs under its body, contracting its cervical spine to the maximum.

NOSTRILS
Very wide, they allow it to receive more oxygen as it runs.

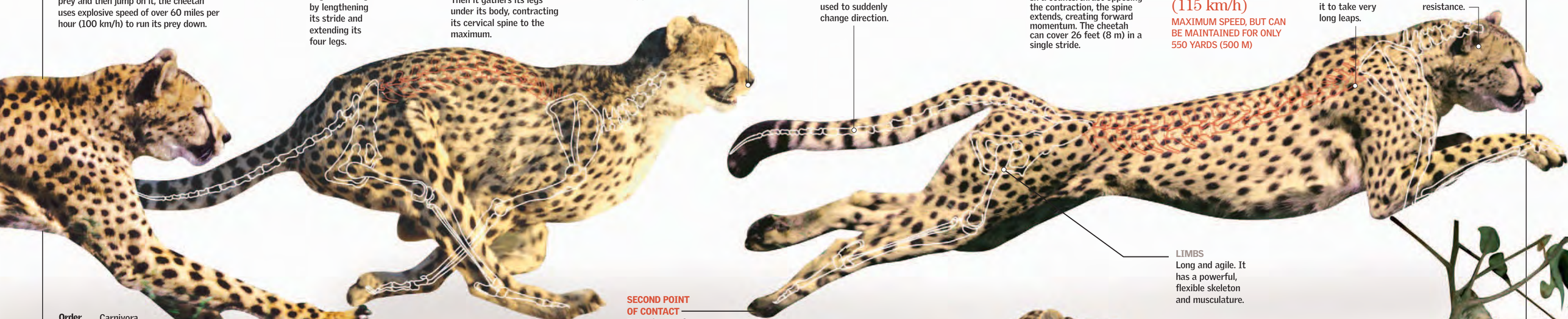
TAIL
Large compared to the rest of the body, it acts as a pivot used to suddenly change direction.

3 EXTENDING THE SPINE
In a counterthrust opposing the contraction, the spine extends, creating forward momentum. The cheetah can cover 26 feet (8 m) in a single stride.

70 miles per hour (115 km/h)
MAXIMUM SPEED, BUT CAN BE MAINTAINED FOR ONLY 550 YARDS (500 M)

SHOULDER
The extensive flexion of the shoulder allows it to take very long leaps.

HEAD
Small and aerodynamic, with low air resistance.



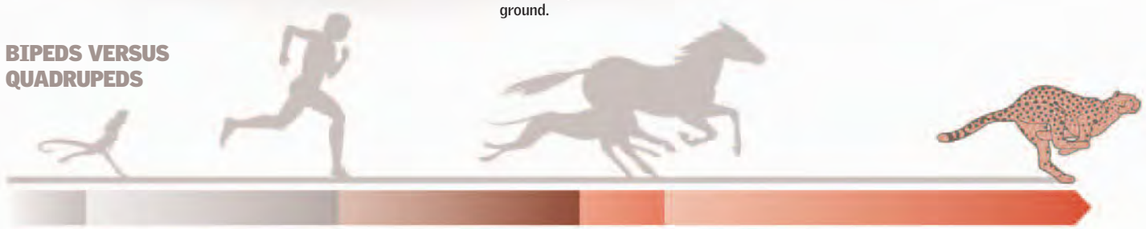
LIMBS
Long and agile. It has a powerful, flexible skeleton and musculature.

FIRST POINT OF CONTACT
As it runs, only one leg touches the ground at a time, but during the cervical contraction, the entire body lifts from the ground.

SECOND POINT OF CONTACT
Extending its four legs again, it picks up more momentum, supporting itself only on one back leg.

Order	Carnivora
Family	Felidae
Species	*Acinonyx jubatus* (Africa) *Acinonyx venaticus* (Asia)

BIPEDS VERSUS QUADRUPEDS



18 MPH (29 KM/H)
SIX-LINED RACERUNNER
Cnemidophorus sexlineatus

23 MPH (37 KM/H)
HUMAN BEING
Track record: Asafa Powell (Jamaica), 110 yards (100 m) in 9.77 seconds

42 MPH (67 KM/H)
GREYHOUND
A dog with a light skeleton and aerodynamic anatomy

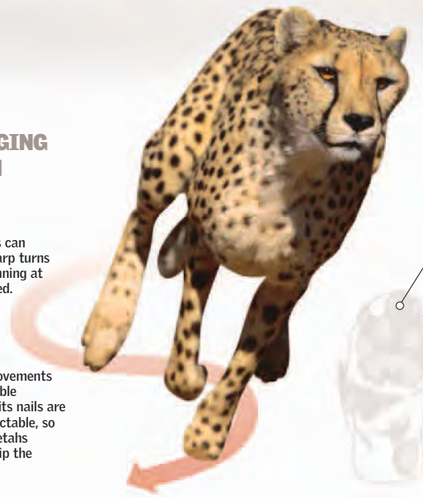
50 MPH (80 KM/H)
HORSE
An anatomy designed for running, powerful musculature

70 MPH (115 KM/H)
CHEETAH
It only takes 2 seconds to reach a speed of 45 miles per hour (72 km/h).

ZIGZAGGING AT HIGH SPEED

1 Cheetahs can make sharp turns while running at high speed.

2 These movements are possible because its nails are not retractable, so that cheetahs firmly grip the ground.



PAWS

DIGITS
5 in the hands
4 in the feet

NAILS
Unlike other felines, their nails are not retractable, allowing them to grip the ground better.

Sloth

These animals are notable for their extremely slow metabolism. They take half a minute to move a limb! They are also somewhat myopic, their hearing is mediocre, and their sense of smell barely serves to distinguish the plants on which they feed. They are at the extreme opposite of cheetahs. However, since they practically live perched in trees, they do not need to move or see or hear precisely. They are perfectly adapted to their way of life.

THREE-TOED SLOTH
Native to the Amazon River basin

Looks That Kill

Tigers are the largest of the world's felines. Predators par excellence, they have physical skills and highly developed senses that they use to hunt for prey. Their daytime vision is as good as that of humans, except for a difficulty in seeing details. However, at night, when tigers usually hunt, their vision is six times keener than that of a human being, because tigers' eyes have larger anterior chambers and lenses and wider pupils.

Seeing Even in the Dark

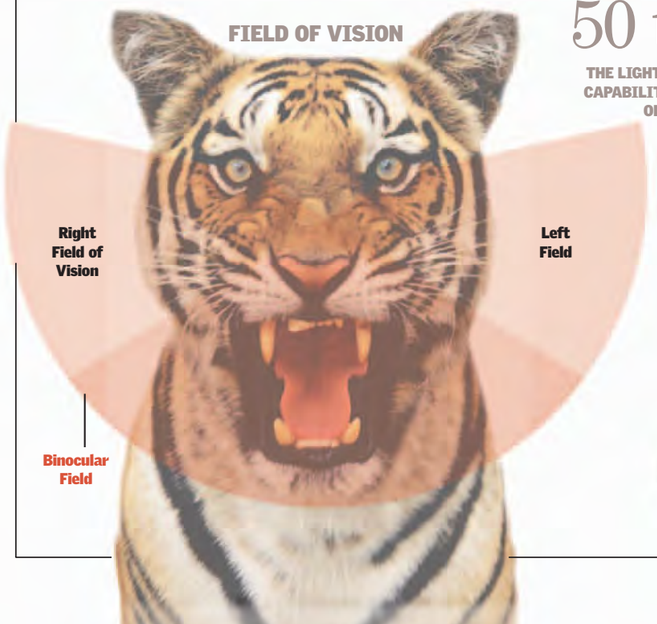
Hunting animals depend on the keenness of their senses to detect their prey. Felines can dilate their pupils up to three times more than humans, and they see best when light is dim and their prey's movements are very subtle. A system of 15 layers of cells forms a sort of mirror (tapetum lucidum) located behind the retina or back of the eye. This mirror amplifies the light that enters and is also the reason that the animal's eyes shine in the dark. At the same time, their eyes are six times more sensitive to light than those of people. Tigers' nocturnal vision also increases because of the great adaptability of their circular pupils when they are completely open.

Tigers have a 255° angle of vision, of which 120° is binocular, whereas humans have 210° with 120° of it binocular.

BINOCULAR VISION

Part of the field of vision of one eye overlaps that of the other eye, which makes three-dimensional vision possible. Hunters' skills depend on binocular vision, because it allows them to judge the distance and size of their prey.

FIELD OF VISION

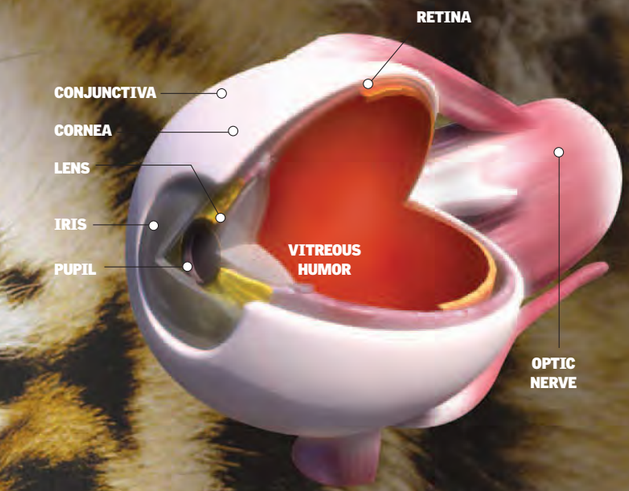


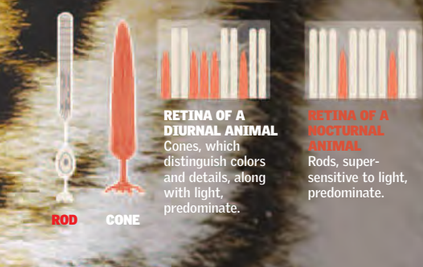
50 times

THE LIGHT AMPLIFICATION CAPABILITY OF THE RETINA OF FELINES

PUPILS

They regulate the passage of light to the retina by contracting in bright light and dilating in the dark. In each species of mammal, the pupils have a distinctive shape.

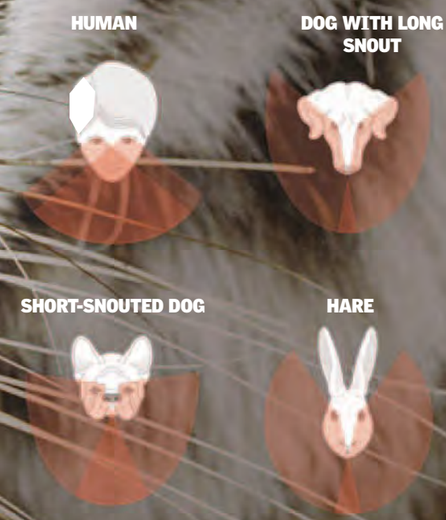




LIGHTS OR COLORS

The retina's sensitivity to light depends on rod-shaped cells, and forms and colors depend on other cells, which are cone-shaped. In tigers, the former predominate.

Field of Vision

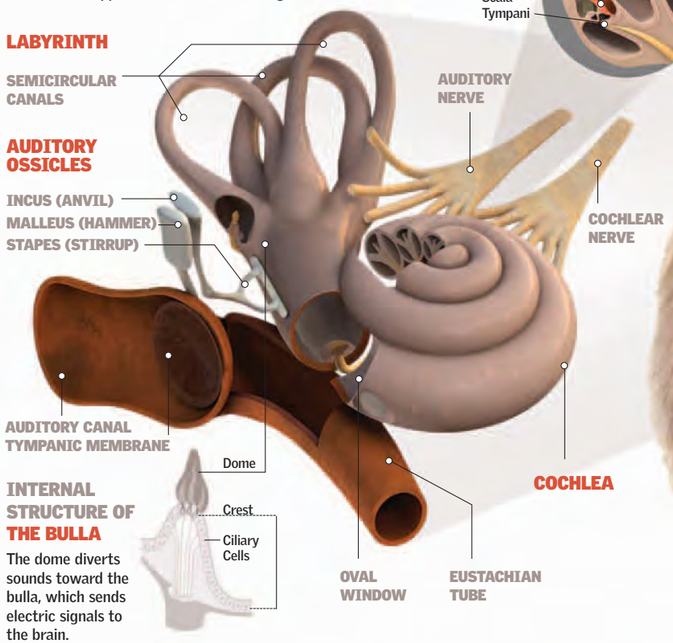


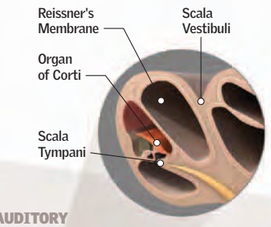
Developed Senses

Dogs have inherited from wolves great hearing and an excellent sense of smell. Both perform an essential role in their relationship to their surroundings and many of their social activities. However, they are very dependent on the keenness of their senses depending on the habitat in which they develop. Whereas humans often remember other people as images, dogs do so with their sense of smell, their most important sense. They have 44 times more olfactory cells than people do, and they can perceive smells in an area covering some 24 square inches (150 sq cm). Dogs can discern one molecule out of a million other ones, and they can hear sounds so low that they are imperceptible to people.

Hearing

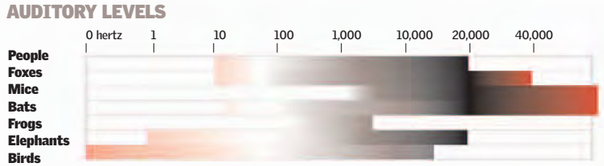
The auditory ability of dogs is four times greater than that of human beings, and it is highly developed. Their ability depends on the shape and orientation of their ears, which allow them to locate and pay closer attention to sounds, although this varies by breed. They can hear sharper tones and much softer sounds, and they can directly locate the spatial reference point where a noise was produced. Dogs hear sounds of up to 40 kilohertz, whereas the upper limit for human hearing is 18 kilohertz.





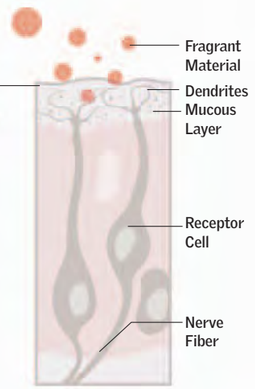
INTERNAL STRUCTURE OF THE BULLA

The dome diverts sounds toward the bulla, which sends electric signals to the brain.



Sense of Smell

Their most developed sense; they have 220 million olfactory cells in their nasal cavities. Mucous tissue, located in the nasal conchae of the snout, warms and moistens the air that they inhale.

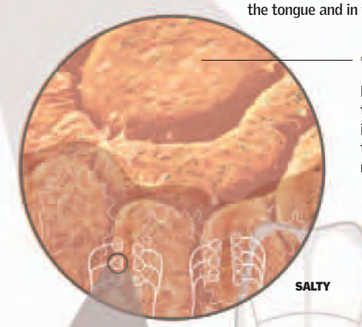


over
1,000 times

THE CAPABILITY OF A DOG'S SENSE OF SMELL COMPARED TO THAT OF A HUMAN

Taste

Dogs perceive the chemical substances that foods are made of by means of receptor cells found in the taste buds located at the back of the tongue and in the soft part of the palate.



TASTE RECEPTORS

Individual receptor cells pass information to the olfactory centers of the brain.

THE TONGUE AND TASTES

Sweet tastes are experienced in the front part of the tongue, sour ones in the center, and salty ones in the back. On either side salty and sweet are mixed.

Soft Contact

Admired, adored, and coveted by humans, a mammal's fur coat is much more than a skin covering. It acts as a protective layer against mechanical injuries, prevents invasion by germs, and regulates the loss of body heat and moisture. In many species, such as the Arctic fox, it provides camouflage by changing color and texture from winter to summer.

Fur and Mimicry

Mammals from cold regions, such as polar bears, have white fur to camouflage themselves in snow. Others, such as polar, or Arctic, foxes and the American hare, change their fur color with the seasons, because they live in areas that are snow-covered in winter, where their brown summer fur would make them easy prey. Lions' beige color helps them avoid being discovered while they stalk their prey.

WINTER
Arctic foxes have two kinds of color phases. White phase foxes are almost pure white in the winter, which allows them to camouflage themselves in the snow and ice.

SUMMER
The fur coat of the Arctic fox (*Alopex lagopus*) in summer is half as thick as that of winter, with less than half the underfur. In summer, "white" phase animals turn a gray-brown to grayish color, and those that have a "blue" phase are browner and darker.

UV FUR SERVES TO PROTECT THE SKIN FROM EXCESSIVE UV RAYS.

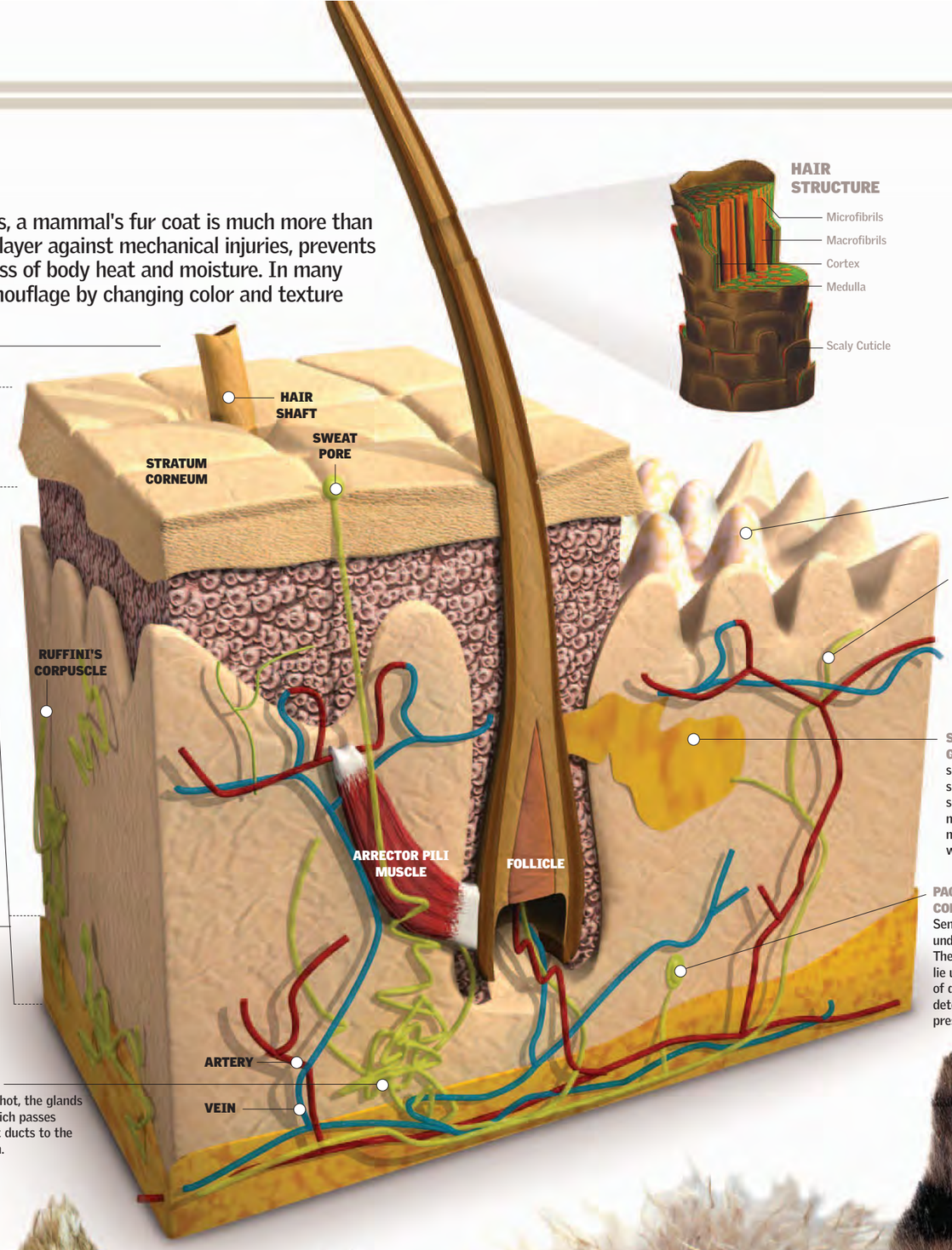
The Skin

EPIDERMIS
Outer layer formed by resistant, flat cells

DERMIS
Layer with blood vessels, glands, and nerve endings. It is a layer of sebaceous glands that secrete an oily substance, sebum, on the surface of the skin.

FATTY TISSUE
This is a specialized conjunctive tissue made up primarily of connective cells called adipocytes, which store energy in the form of triglycerides.

SWEAT GLANDS
When the body is hot, the glands secrete sweat, which passes through the sweat ducts to the surface of the skin.



DERMAL PAPILLA
attaches the dermis to the epidermis.

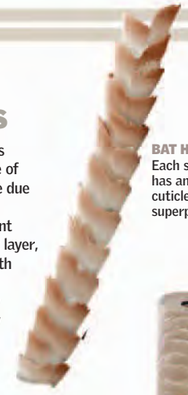
MERKEL'S DISK
A sense receptor under the skin's surface that responds to light, continuous touch and pressure

SEBACEOUS GLAND
secretes a waxy substance, or sebum, which moistens the skin, making it waterproof.

PACINIAN CORPUSCLE
Sense receptors under the dermis. The Pacini receptors lie under the layer of deep fat and detect vibration and pressure.

Diverse Hairs

The majority of mammals' fur is made up of more than one type of hair, and its different colors are due to a group of proteins called melanins. Each coat has different layers. Guard hairs are the first layer, providing protection. Underneath that, there is a fine layer called underfur, formed by constantly growing short hairs that renew the coat.

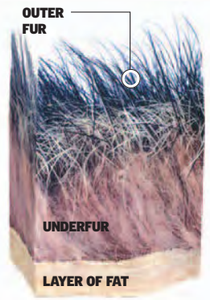


BAT HAIR
Each strand of hair has an outer cuticle formed by superposed scales.

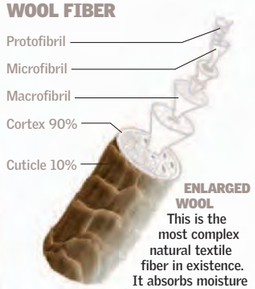
POLAR BEAR HAIR
Each one of its hairs is hollow and filled with air. This heightens the insulating capability of the inner layer.

Insulating Skin

Insulation is one of the functions of animals' skins and hair. It not only helps to conserve body warmth but also, as in the case of camels, protects them from excessive heat. Its color often blends in with its surroundings, serving as camouflage.



WOOL FIBER

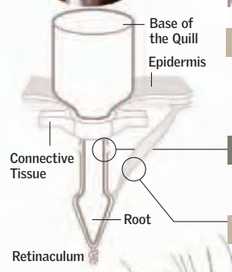


ENLARGED WOOL
This is the most complex natural textile fiber in existence. It absorbs moisture but repels water.

PORCUPINE QUILLS
Called guard hairs, they are located outside the fur. In the case of the porcupine, they have been modified to form defensive quills.

30,000
THE NUMBER OF QUILLS THAT COVER A PORCUPINE (148 PER SQUARE INCH [23 PER SQ CM])

ERECTION MECHANISM



1. When the quill touches a strange surface, it exerts a light downward pressure on the epidermis.
2. The fine tissue that covers the root of the quill breaks.
3. The erector pili muscle receives the contact signal and contracts.

Behavior and Life Cycle

EAT TO LIVE
An hour after birth, the giraffe gets up and with its 8 feet (2.5 m) of height begins to take its first steps in search of its mother's teat.

LIFE CYCLE 34-35
BEAUTY AND HEIGHT 36-37
OVIPAROUS MAMMALS 38-39
EFFICIENT NURSERY 40-41
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THE FIRST DAYS 44-45
TRADEMARK 46-47
DEVELOPMENT AND GROWTH 48-49
OF FLESH THOU ART 50-51
HERBIVORES 52-53
THE GREAT CHAIN 54-55
ONE FOR ALL 56-57
WOLVES IN SOCIETY 58-59

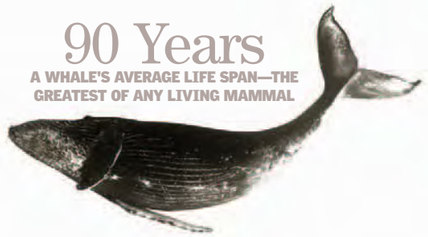
Mammalian reproduction is sexual and by internal fertilization, which involves copulation between the male and the female. Mammals are also characterized by the offspring's dependence on its parents. In any case, there is a group of mammals called monotremes that is oviparous; that is, its members reproduce by laying eggs. Mammalian behavior consists of a mixture of inherited components and components that can be shaped by learning. Part of this process is accomplished through play, since the young use such encounters to practice jumping, biting, hunting, and other survival skills. You will discover this and much more when you turn the page.●

Life Cycle

Birth, maturity, reproduction, and death: this life cycle has certain particularities among mammals. As a general rule, the larger a mammal, the longer the members of its species tend to live but the fewer offspring are born to a single female per litter or reproductive season. Most mammals, including humans, are placental mammals; their vital functions are fully developed inside the body of the mother. ●

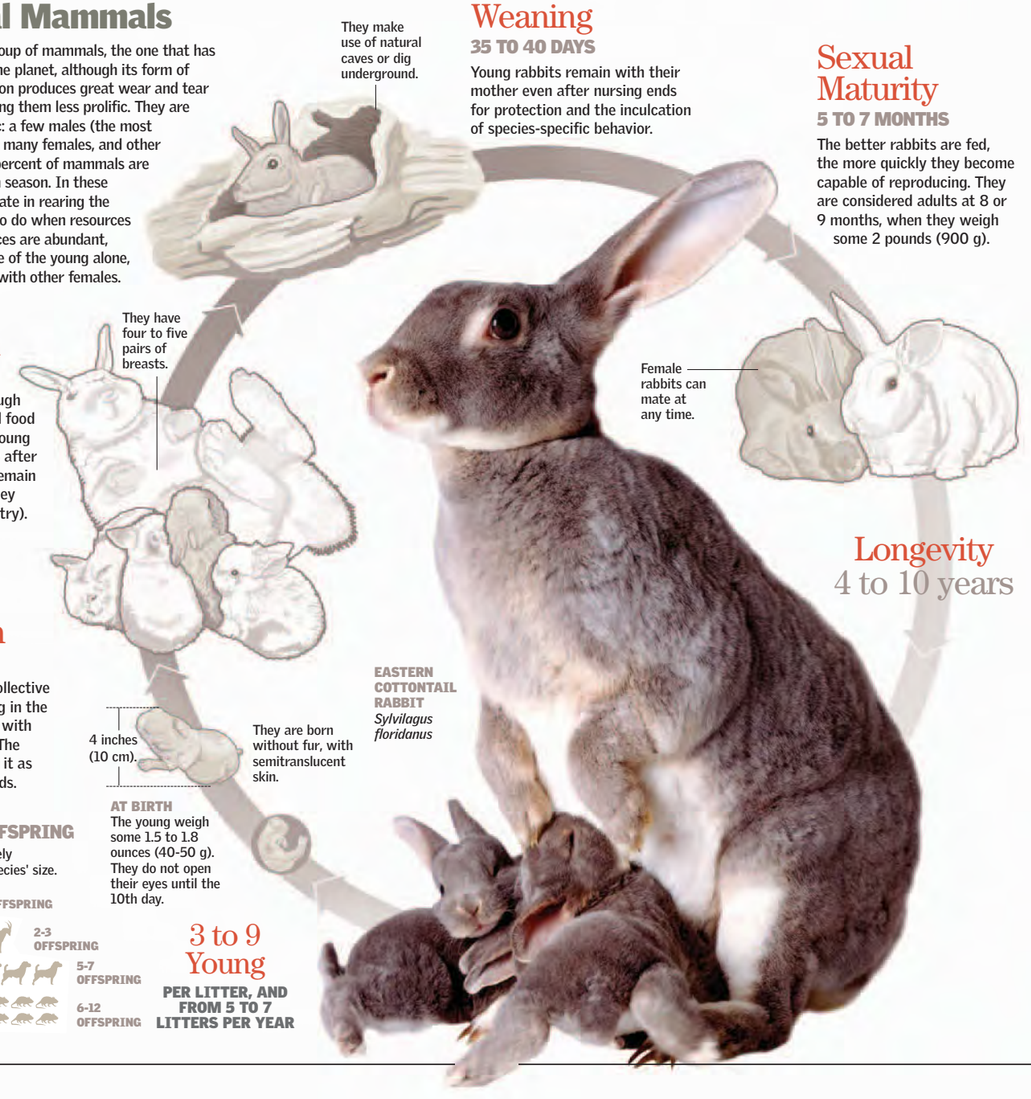
90 Years

A WHALE'S AVERAGE LIFE SPAN—THE GREATEST OF ANY LIVING MAMMAL



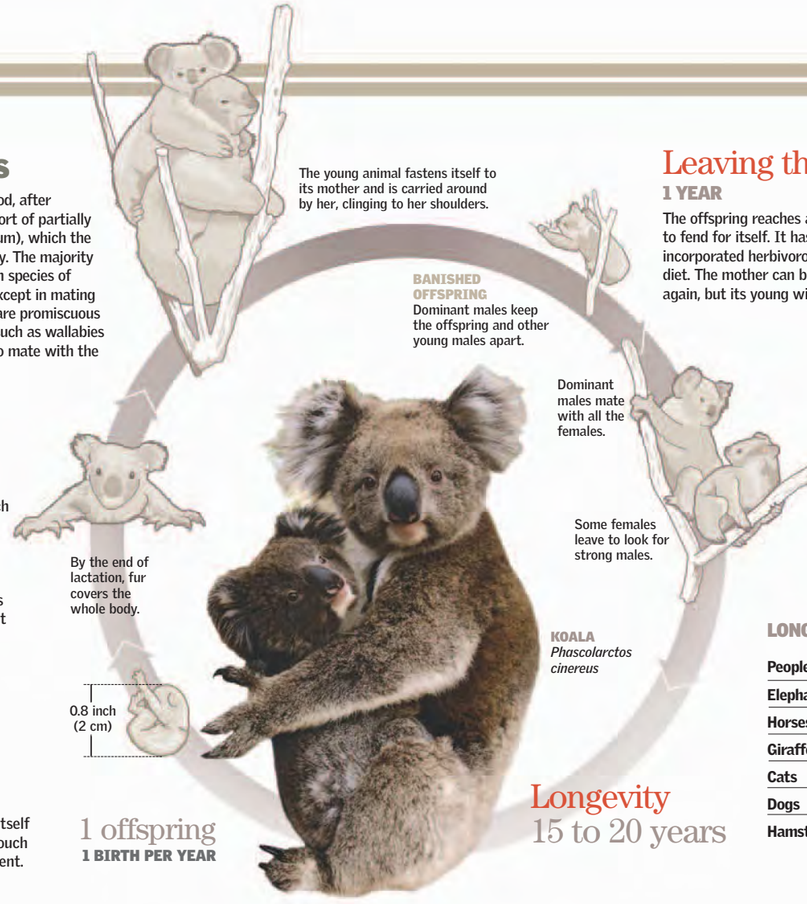
Placental Mammals

This is the largest group of mammals, the one that has multiplied most on the planet, although its form of gestation and lactation produces great wear and tear on the females, making them less prolific. They are generally polygenetic: a few males (the most competitive) fertilize many females, and other males, none. Only 3 percent of mammals are monogamous in each season. In these cases, males participate in rearing the offspring, as they also do when resources are scarce. If resources are abundant, the females take care of the young alone, and the males mate with other females.



Marsupials

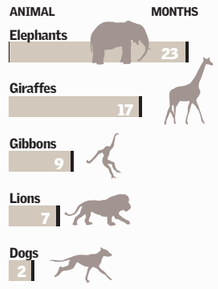
Very short gestation period, after which they develop in a sort of partially open pouch (the marsupium), which the female carries on her belly. The majority of the roughly 300 known species of marsupials are solitary, except in mating periods. In general, they are promiscuous animals, although some, such as wallabies (small kangaroos), tend to mate with the same female all their life.



LONGEVITY

People	70 years
Elephants	70
Horses	40
Giraffes	20
Cats	15
Dogs	15
Hamsters	3

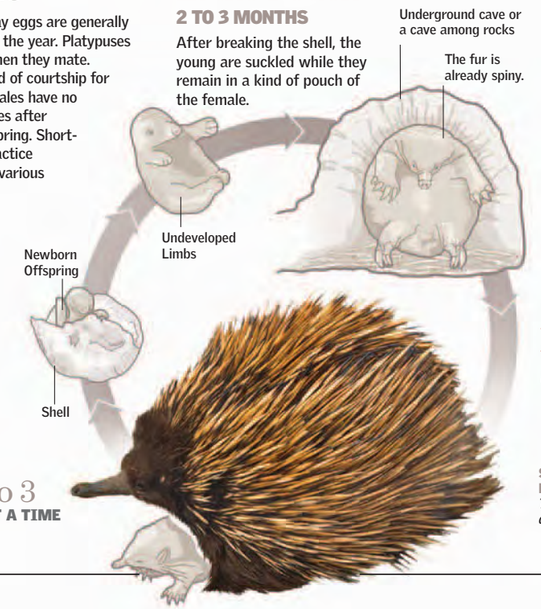
GESTATION PERIODS



COMPARISON OF EGG SIZE

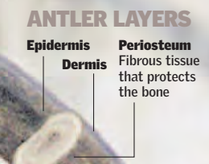
Monotremes

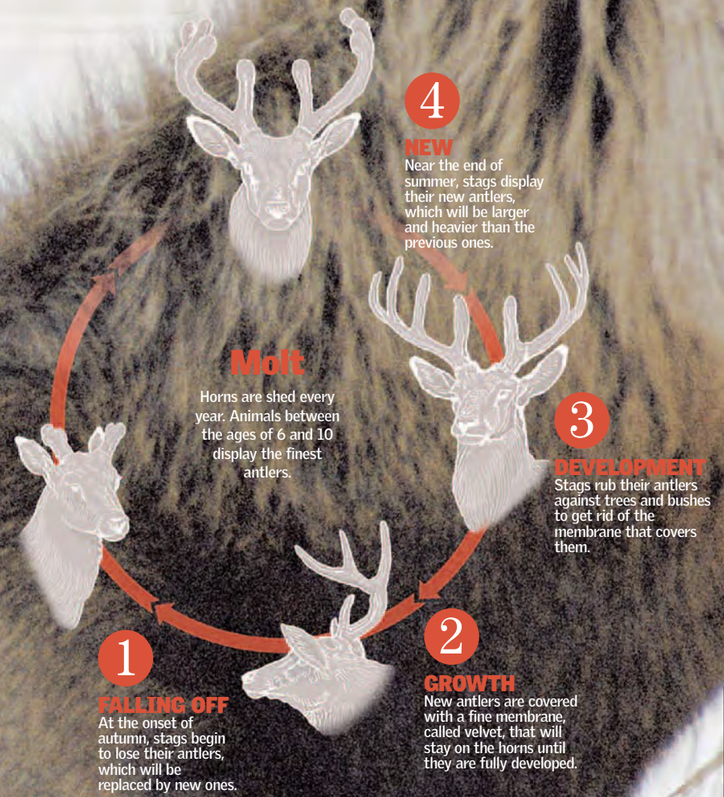
Mammals whose females lay eggs are generally solitary species for most of the year. Platypuses are seen as couples only when they mate. Although they have a period of courtship for one to three months, the males have no relationship with the females after copulation or with the offspring. Short-beaked echidna females practice polyandry, copulating with various males in various seasons.



Beauty and Height

Finding a female with whom to mate is the great effort of the male's life, a competition with other males of his own species. Each animal has its particular nuances. For stags, antlers play a fundamental role in winning the heart of their chosen one. Whichever stag has the most beautiful, longest, and sharpest horns will be the winner. Thus, he will be able to defend his territory, court the female, and reproduce.





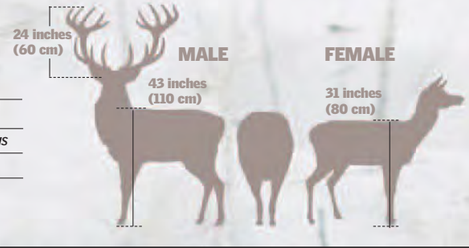
Red Deer

These are svelte, robust, well-formed animals with a majestic and haughty carriage. They are very timid and fearful, and it is thought that the species is 400,000 years old. They are active at daybreak and evening, and males usually live alone. Females and younger deer group in herds.

Order	Artiodactyla
Family	Cervidae
Species	*Cervus elaphus*
Diet	Herbivorous
Weight (male)	400 pounds (180 kg)

Fights

When two males fight over a harem, each will display his antlers to frighten his rival. The horns can also be used to defend against predators.



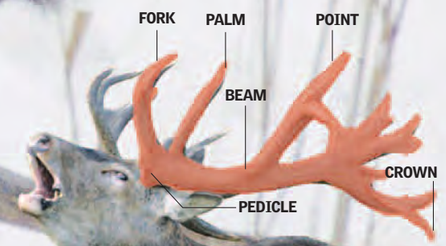
Horns and Antlers

Horns are outgrowths of the cranium, covered by a tegument that forms a sheath. They appear in bovids of both sexes and are generally permanent. Antlers are also extensions of the cranium; they are limited to the deer family, are present only in males, and are replaced annually.

Bellows

Sonorous and discordant, they begin to be heard when spring arrives, announcing the beginning of rut, or mating season. They not only attempt to keep competitors away with their call but they also use the sound to attract unattached females to join the male's herd.

Antlers



Oviparous Mammals

For a mammal to lay eggs seems improbable, but the surprising monotreme females, instead of giving birth to young, are oviparous. They are warm-blooded, have hair, and feed their newborn through mammary glands despite having no nipples. Platypuses seem like a cocktail of nature, inasmuch as parts of their bodies resemble those of other types of animal. The other monotremes, echidnas, are covered with spines, and their young grow in the mother's pouch.

Platypus

Combining the skin of a mole, the tail of a beaver, the feet of a frog, and the beak of a duck, platypuses are semiaquatic mammals endemic to the eastern part of Australia and to the island of Tasmania. They construct burrows in riverbanks consisting of a long passageway.

Family	Ornithorhynchidae
Species	*Ornithorhynchus anatinus*
Diet	Herbivorous
Weight	5.5 pounds (2.5 kg)

16 TO 24 INCHES (40-60 CM)

BILL
has sensitive electroreceptors that can perceive the electric field generated by the muscles of their prey.

100 feet
(30 m)
HOW LONG THE BURROW OF A PLATYPUS CAN BE

Echidna

Lives in Australia, New Guinea, and Tasmania. It has an elongated snout in the form of a beak, no teeth, and a long, retractable tongue. It is a notable digger and hibernates underground. Echidnas can live up to 50 years, and their hair varies according to the species.

Family	Tachyglossidae
Species	*Tachyglossus aculeatus*
Adult Size	

12 TO 35 INCHES (30 TO 90 CM)

RETRACTABLE TONGUE
A sticky substance on the long and slender tongue allows it to catch termites and ants.

Reproductive Cycle

The platypus has three reproductive cycles annually and spends most of the year in solitude. Platypuses are seen as couples only when they mate. They have a period of courtship before copulation, which is performed by a juxtaposition of cloacae. Their reproductive rate is low since they lay only one to three eggs. The female platypus digs a burrow before laying her eggs, whereas echidnas have a pouch in which they incubate their young. Unlike the hair on the other parts of its body, the hair in the echidna's pouch is soft.

1 Conception
For reproduction, the female makes a deep burrow, where it hides. It lays the eggs when it finishes digging the burrow.

2 Incubation
The eggs are covered by a soft shell, and incubation lasts two weeks.

3 Birth
When the egg breaks, the upright position of the mother allows the offspring to find the mammary areas.

4 Lactation
The mother has no nipples, but milk comes out through pores in her abdomen, from which the offspring suck.

5 Weaning
After 16 weeks, the young begin to feed on ants and other small insects.

EYES
are kept closed underwater.

SNOUT
is used to search for and catch food.

LIMBS
have claws at the tips of their feet, which help in digging rapidly.

HAIR
The sharp spines originate within the fur.

The Cycle

1/3 inch (9 mm)

A The egg is the size of a grape and stays at the bottom of the female's incubating pouch. It takes 11 days to hatch.

B When born, it is one half inch long. The front feet hold on to the mother's pouch, where it crawls in search of food.

C Seventy days later it will leave the mother's pouch, and the mother will place it in a burrow, where she will feed it for three more months.

Efficient Nursery

Marsupial females carry their newborn offspring in their marsupium, a pouch attached to their belly. The offspring are not very well developed when they come into the world after a gestation period that varies from two to five weeks. Upon emerging, the offspring must immediately climb with their front paws to the marsupium to survive. Once inside, they will be protected. They are continually supplied with milk through their mother's four teats, helping them complete their growth before leaving the pouch for the outside world.

Red Kangaroos

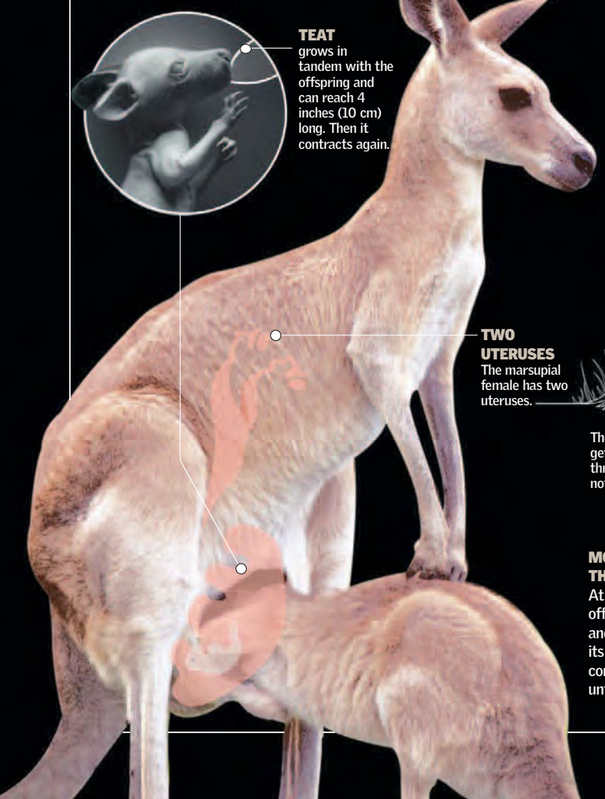
Kangaroos are a family comprising several groups, including great wallabies and tree-dwelling kangaroos. Kangaroos, the prototypical marsupial, live in Australia and in Papua New Guinea, never more than 9 miles (15 km) from water. They have large, muscular hind legs that they use to take great consecutive leaps, reaching speeds of 15 to 20 miles per hour (24-32 km/h). They are able to maintain their balance standing only on their hind legs. Their heel bone (calcaneus) is long and acts as a lever.

Family Macropodidae

Species *Macropus rufus*

Females are half this size.

TEAT grows in tandem with the offspring and can reach 4 inches (10 cm) long. Then it contracts again.



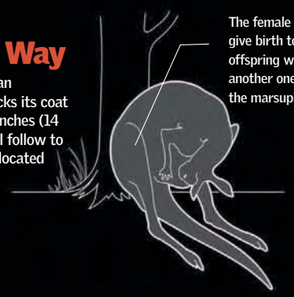
TWO UTERUSES The marsupial female has two uteruses.

MOVING OUT OF THE MARSUPIUM At eight months, the offspring leaves the pouch and begins to add grass to its diet, but it will continue to be suckled until it is 18 months old.

REPRODUCTIVE CYCLE

1 Smoothing the Way

When preparing for the birth of an offspring, the female kangaroo licks its coat to form a kind of path some 5.5 inches (14 cm) long, which the offspring will follow to reach the entrance to the pouch located higher up on the belly.



The female can give birth to an offspring while another one is in the marsupium.

2 A Marathon

Small kangaroos are born after a few weeks of gestation in an early stage of their development, weighing less than 0.2 ounce (5 g). They cannot see or hear. They only move their front paws, with which they drag themselves, following their mother's trail of saliva and guided by their sense of smell.

The baby kangaroo must get to the pouch within three minutes or it will not survive.

3 Lactation

Upon reaching the marsupium, the baby fastens its mouth upon one of the four teats inside. At this point, the baby is red and looks very fragile. However, it will grow continuously over the next four months, during which it will not leave the pouch.

Entering the Marsupium

A After some eight months, the kangaroo can leave the marsupium. But it returns to be suckled and protected.

B However, it barely fits. It enters head first with the aid of its front paws and turns around once inside the pouch.

C When it is already alternating milk with grass from outside, the young kangaroo sticks its head out to eat grass without leaving the pouch.

0.8 inch (20 mm)

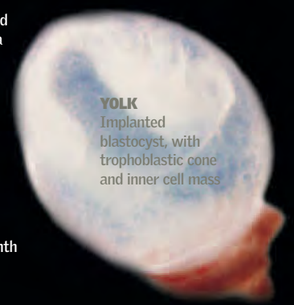
THE SIZE OF AN OFFSPRING WHEN IT ENTERS THE MARSUPIUM

Miraculous Placenta

The largest reproductive group is formed by placental mammals, in which the unborn offspring develop in the female's uterus. During gestation, food and oxygen pass from the mother to the fetus through an organ known as the placenta, which allows the exchange of substances through the blood. At birth, the offspring often have no hair, are deaf and blind, and feed on milk secreted by the female's mammary glands, which become active after birth.

Gestation of Rats

Gestation lasts between 22 and 24 days. Whereas the placenta is discoid and hemochorial, the ovaries are essential for maintaining gestation. If an ovariectomy is performed at any stage of gestation, it will always bring about a miscarriage or the reabsorption of the fetuses since the placenta does not produce sufficient progesterone to maintain gestation. The growth of the uterine horns becomes visible on the thirteenth day of gestation.



1

1 to 2 Days

Rat embryo at the two-cell stage. By the second day, it will have four cells, and on the third day, it will enter the uterus.

2

4 to 5 Days

At this point, the embryo is composed of four cells and is covered with a thin layer of glycoprotein. It implants itself in the uterus.

3

6 to 8 Days

The blastocyst has now implanted and established itself in the uterus. The fetus begins to form, and the blastocyst becomes a yolk sac.

Uterus

IS BICORNUATE AND HAS TWO CERVICES.

Placenta

From whales to shrews, placental mammals are characterized by gestating their young inside the mother and giving birth when they are well developed. To do so, they have a special organ, the placenta. This is a spongy tissue that completely surrounds the embryo, allowing the exchange of substances through the blood. In this way, the mother can transfer nutrients and oxygen to the embryo, at the same time that she absorbs the metabolic waste of her future offspring. After birth, the placenta is immediately devoured by the mother, who uses her teeth to help the young leave the structure.

4

11.5 Days

The embryo has now fastened itself to the embryonic sac (a sort of balloon that covers the fetus) and to the placenta. The brain, eyes, and legs begin to form.

5

14.5 Days

Eyes and extremities are now visible, and the internal organs begin to develop. A pre-cartilaginous maxillary and the outer ear begin to form.

6

17.5 Days

The eyelids grow very rapidly, and within a few hours the eyes will be completely covered. The palate has already completed its development, and the umbilical cord retracts.

7

19.5 Days

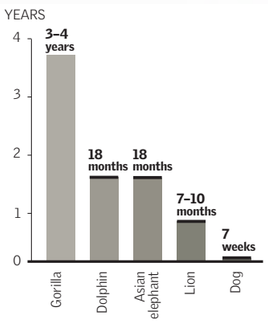
Only a few days are left before the female will give birth to a new litter of little rats. At birth, they are helpless despite the fact that all their organs are developed.

The First Days

Mammals whose offspring develop within the uterus devote a lot of attention to their young compared to other animals, because their pups are unable to live on their own at birth. That is why they are cleaned, fed, and warmed. Dogs have various developmental stages. First is the neonatal stage, which lasts from the opening of the pups' eyes until they begin to hear. Then comes the socialization stage, which runs from days 21 to 70, and, finally, the juvenile stage, from 70 days on.

Lactation Period

This period is essential in the reproductive process of mammals. The young of most placental mammals are totally dependent in the first stages of their life on mammary milk secretion.



Birth

Like humans, dogs develop slowly after birth, because they are not fully developed when they come into this world and are incapable of living on their own. They need a structured environment in which they are cared for by their parents and other members of the pack.

Birth

The first pup is born between 1 and 2 hours after contractions begin.

WET HAIR
Once dry, pups seek a teat from which to suck colostrum, which consists of, among other things, immunological substances.

MEMBRANE
Placenta, which covers the pup

Litter
3 to 8 Offspring

The mother knows each newborn and realizes if any pup is taken away from her.

MAMMARY GLANDS

EYES
remain shut until the second or third week.

THE DEN
The mother builds a den in a warm place away from noise.

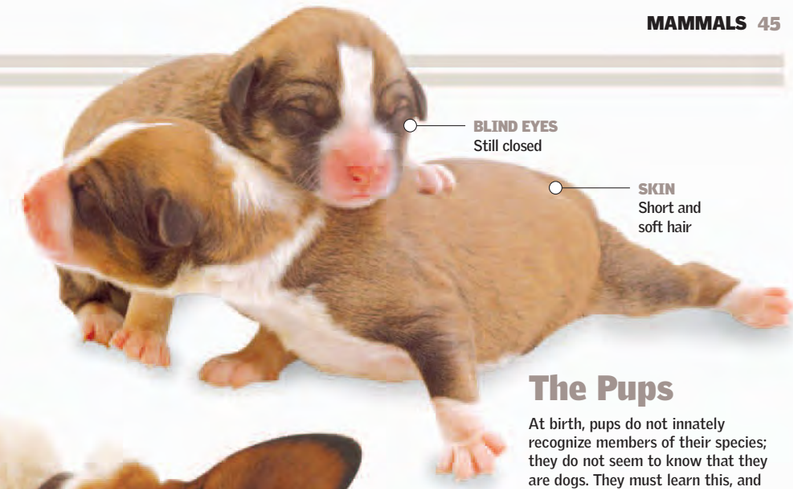
SURPRISE REFLEX
At 20 days, pups start to hear and react to sound.

TACTILE REFLEX
They push with their snout until they are hidden.

EXTENSOR REFLEX
At 12 days, pups extend their hind legs when picked up.

Up to 20 Days

This period, in which pups depend totally on the mother, lasts from birth to 15 or 20 days, when the pups open their eyes. But until then, they are completely dependent on their mother, seek contact with the mammary glands, and whimper if they are alone. They have little ability to keep themselves warm, and they even need the stimulation of their mother to pass body wastes.



BLIND EYES
Still closed

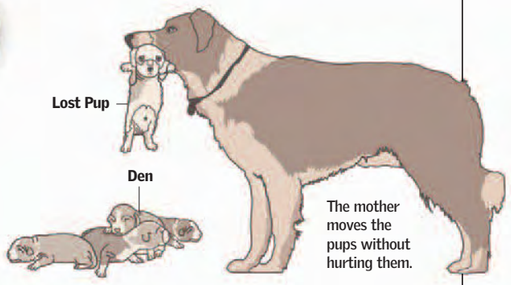
SKIN
Short and soft hair

The Pups

At birth, pups do not innately recognize members of their species; they do not seem to know that they are dogs. They must learn this, and the mother and the rest of the litter are in charge of teaching them this.

THE MOTHER'S POSITION
The mother lies down to make it easier for the pups to reach her.

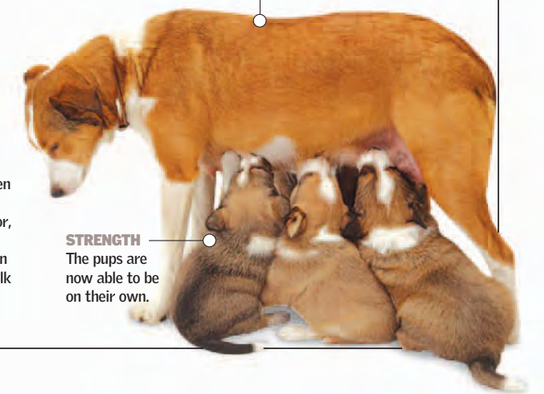
TRANSPORT
To move her weak pups, which cannot yet walk, the mother picks them up by the skin on the napes of their necks and places them in the den. Fifteen days after birth, mother dogs experience what is called the bonding phenomenon: they become aware of the litter's existence, see them as a group, and notice if any puppy is missing.



The mother moves the pups without hurting them.

THE MOTHER
The relationships of pups to their mother and siblings are essential to dogs' later development, because, although their social structures and relationships are largely innate, they must be shaped, tested, and practiced to develop properly.

STANDING UP
The mother no longer needs to lie down and is free to move away.



STRENGTH
The pups are now able to be on their own.

From Day 21 to Day 70

Natural weaning involves offering pups predigested food as a replacement for milk. When the mother comes back from hunting, its mouth has an odor, and the pups, stimulated by the odor, smell her, lick her snout, rub it, and nibble her jaws and face, which stimulates the regurgitation of food. At this stage, in which the pups have milk teeth, they can begin to eat these foods.

Trademark

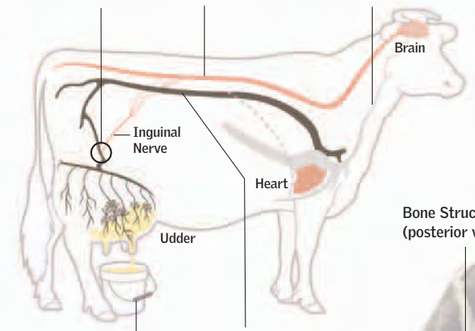
The exclusive characteristic of mammals, the one that immediately identifies them, is the presence of milk-producing glands with which the females of all mammalian species feed their offspring after they are born. The number and arrangement of mammary glands vary by species. Teats are arranged in pairs and are present in both sexes, although only females possess functional mammary glands—and that only while lactation lasts.

How a Cow Gives Milk

1 First impulse: With **suction**, the neurohormonal reflex related to lactation generates a nerve impulse.

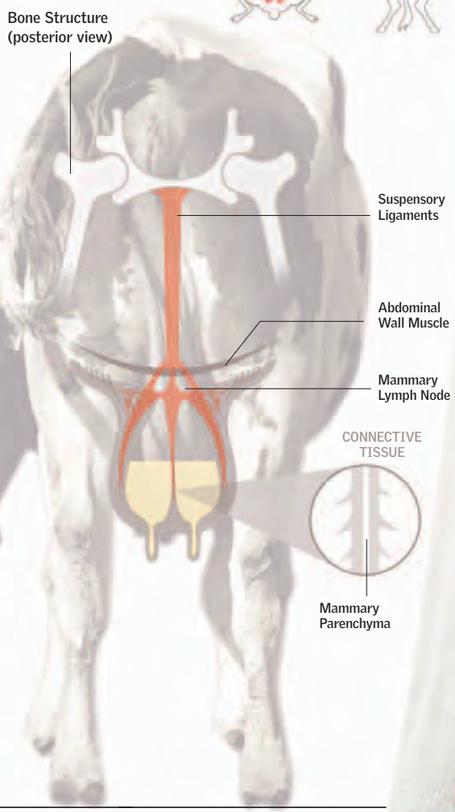
2 This impulse is transmitted by the inguinal nerve to the **spinal cord** and from there to the brain.

3 The brain gives off oxytocin, sending a signal to the heart through a branch of the **jugular vein.**

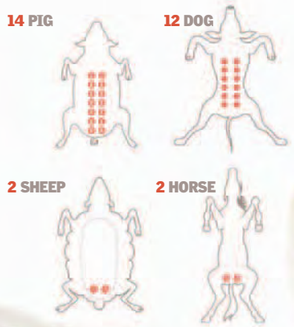


5 **Milk ejection** in the udder is produced by the contraction of myoepithelial cells, which constrict the alveoli.

4 The hormone is distributed to the entire body through the arterial system. This is how it reaches the heart and then the udder.



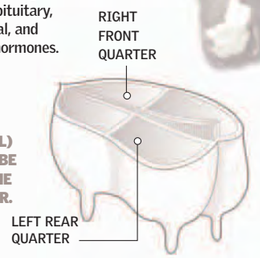
NUMBER OF MAMMARY GLANDS IN FEMALE MAMMALS

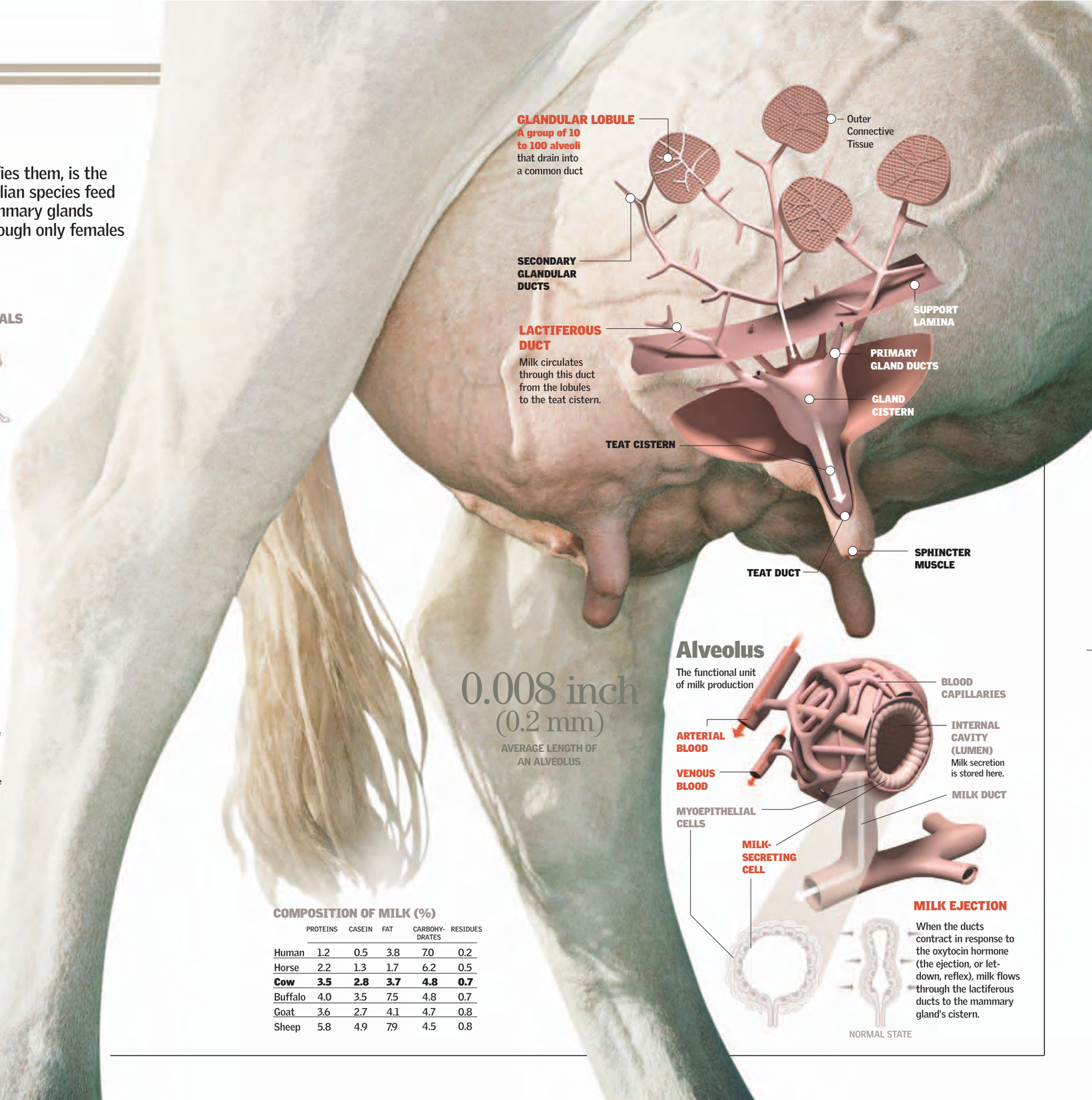


Udder

Cows and mares have two mammary glands that together form an udder. It begins to function after birth and stops when the offspring stop nursing. It is regulated by pituitary, thyroid, placental, and adrenocortical hormones.

4
GALLONS (15 L) OF MILK CAN BE STORED IN THE BOVINE UDDER.





0.008 inch (0.2 mm)
AVERAGE LENGTH OF AN ALVEOLUS

COMPOSITION OF MILK (%)

	PROTEINS	CASEIN	FAT	CARBOHY-DRATES	RESIDUES
Human	1.2	0.5	3.8	7.0	0.2
Horse	2.2	1.3	1.7	6.2	0.5
Cow	**3.5**	**2.8**	**3.7**	**4.8**	**0.7**
Buffalo	4.0	3.5	7.5	4.8	0.7
Goat	3.6	2.7	4.1	4.7	0.8
Sheep	5.8	4.9	7.9	4.5	0.8

Alveolus

The functional unit of milk production

MILK EJECTION

When the ducts contract in response to the oxytocin hormone (the ejection, or let-down, reflex), milk flows through the lactiferous ducts to the mammary gland's cistern.

Development and Growth

Play is much more than entertainment for young mammals. This activity, which may appear to have no specific purpose, is the way in which they learn to be part of their species in the early stages of their lives, simultaneously acquiring the basic means of survival. In their games, chimpanzees perform primary instinctive activities that, with time and improvement, will become perfected instinctive activities. These include using tools, balancing in trees, and forming communication. Young chimpanzees express themselves by means of sounds, facial gestures, and body postures they imitate from adults. Play also allows them to develop their muscle strength and achieve good motor coordination. ●

over **15** **TYPES OF CALLS**

are emitted by chimpanzees, including its pant-hoot: screams and grunts that can be heard a mile and a quarter (2 km) away. Pant-hoots are unique to the individual and can help to identify each member of the group.

This expression communicates terror.

This expression transmits submission.

This gesture indicates worry.

Communication

Some mammals, especially chimpanzees, communicate through facial expressions. This ability is well developed in the young primates, which express fear, submission, and worry, among other feelings.

Games

What we humans call play appears to be limited only to mammals, because they have well-developed senses, intelligence, and the ability to learn. It is through play that mammals carry out their learning.

Social Relations

Play also helps encourage apes to identify with their species. It provides a basis for learning to communicate through the use of sounds and body posture to express, for example, submission or domination.

IDENTIFICATION
Only 15 minutes of play with peers per day will moderate the effects of social isolation.

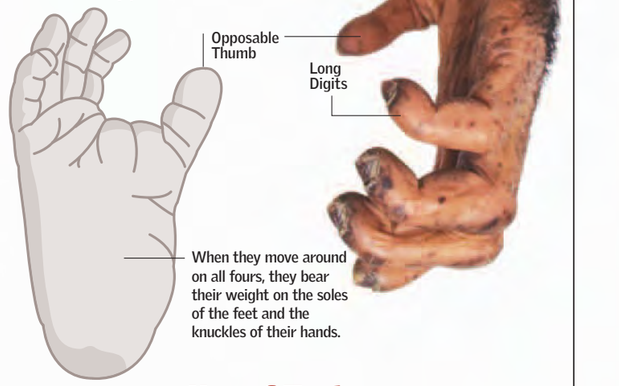
Survival

Play also functions as a method of learning to survive in a wild habitat. It trains carnivores in hunting techniques and herbivores in detecting, and fleeing from, danger.

A LIFE OF HANGING
A great entertainment for apes is hanging from trees. This exercise improves their coordination and arm strength.

Extremities

Chimpanzees are characterized by their long arms, which are endowed with great strength, and by their opposable thumbs. The digits of their hands and feet are large, allowing them to climb with great ease. They can hold onto a branch with their foot while they pluck its fruit with their hand.



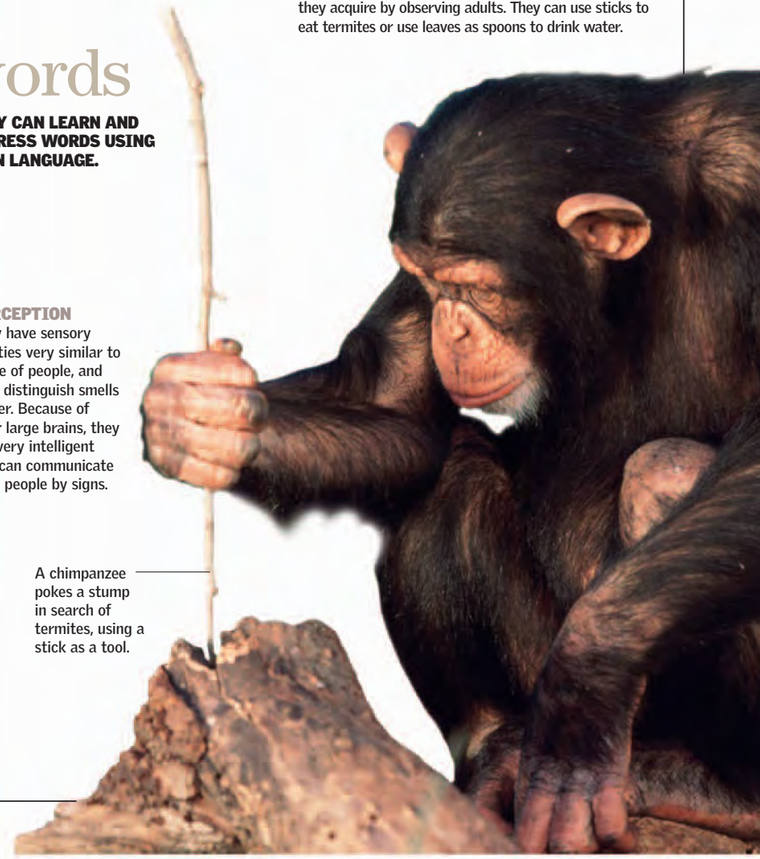
Use of Tools

The use of tools is not common in mammals. However, chimpanzees are capable of using objects as tools, a skill they acquire by observing adults. They can use sticks to eat termites or use leaves as spoons to drink water.

words

THEY CAN LEARN AND EXPRESS WORDS USING SIGN LANGUAGE.

PERCEPTION
They have sensory abilities very similar to those of people, and they distinguish smells better. Because of their large brains, they are very intelligent and can communicate with people by signs.



A chimpanzee pokes a stump in search of termites, using a stick as a tool.

Of Flesh Thou Art

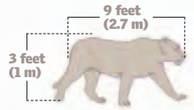
The carnivore group is composed of species whose diet is based on hunting other animals. The kind of teeth they have help them efficiently cut and tear the flesh of their captured prey. Lions, the most sociable of the felines, have good vision and sharp hearing; they live in packs, and when they go hunting, they do so as a group.

Lions

are characterized by a strong, muscular physique. A male requires 15.5 pounds of meat (7 kg) a day, whereas a female needs 11 pounds (5 kg). They have a short digestive tract, which rapidly absorbs nutrients from the ingested meat.

Family	Felidae
Species	*Panthera leo*
Weight	265-410 pounds (120-185 kg)

Size (female)



SIGHT
Their vision is six times better than that of humans. They also have binocular vision, essential for locating prey.

COAT
Short, with a uniform brown color. They have an off-white tuft of hair on the chin.

Main Prey

The bulk of their diet consists of large mammals, although they also catch small mammals, birds, or reptiles when the opportunity arises. They are not scavengers. They generally eat only fresh meat, something they have killed or succeeded in taking away from another predator.

THE TAIL
Measures some 35 inches (90 cm) in length and allows them to keep their balance while running. They also use it to shoo away flies.

40 pounds (18 kg)
OF MEAT CAN BE EATEN BY A LION IN A SINGLE MEAL.

Teeth

UPPER PREMOLARS

UPPER CANINE

UPPER INCISORS

CARNASSIAL MOLAR
They are very large, and the dental crowns are two long blades arranged as shears that fit into each other. Together they slice and cut flesh to perfection.

ANTERIOR PREMOLARS

LOWER CANINE

LOWER INCISORS

The Hunt

1 LYING IN AMBUSH
Hidden in the grass, the lioness silently approaches the prey. Other females wait in hiding.

2 ACCELERATION
When only a few yards away, it starts running to catch the zebra. It exceeds 30 miles per hour (50 km/h), and the other lionesses cooperate in the hunt.

3 LEAP
The lioness hurls the weight of her body on the zebra's neck, trying to knock it down; if she succeeds, the hunt will be successful.

4 LETHAL BITE
The prey falls, and the lioness sinks her fangs into the neck until she kills it. The other females approach.

Herbivores

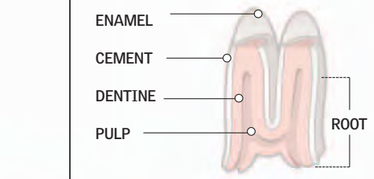
Ruminants, such as cows, sheep, or deer, have stomachs made of four chambers with which they carry out a unique kind of digestion. Because these animals need to eat large quantities of grass in very short times—or else be easy targets for predators!—they have developed a digestive system that allows them to swallow food, store it, and then return it to the mouth to chew calmly. When animals carry out this activity, they are said to ruminate.

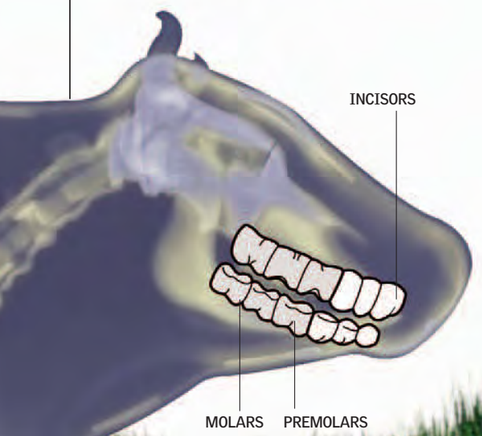
KEY

- INGESTION AND FERMENTATION
- RUMINATION
- REABSORPTION OF NUTRIENTS
- ACID DIGESTION
- DIGESTION AND ABSORPTION
- FERMENTATION AND DIGESTION

Teeth

Herbivorous animals such as horses and bovids have molars with a large flat surface that reduces food to pulp, as well as incisors for cutting grass. Grinding is also done by the molars.





Cows wrap their tongues around the food.

Then they chew it with lateral movements.

1

Cows lightly chew grass and ingest it into their first two stomachs: the rumen and the reticulum. Food passes continually from the rumen to the reticulum (nearly once every minute). There various bacteria colonies begin fermenting the food.

2

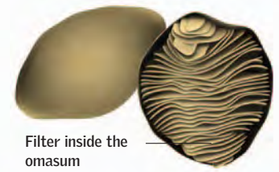
When cows feel satiated, they regurgitate balls of food from the rumen and chew them again in the mouth. This is called rumination; it stimulates salivation, and, as digestion is a very slow process, cows make use of rumination to improve their own digestion together with the intervention of anaerobic microorganisms such as protozoa, bacteria, and fungi.

40 gallons (150 l)
OF SALIVA ARE PRODUCED DAILY IN THE PROCESS.

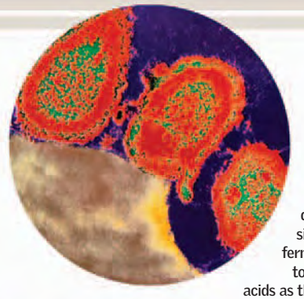
3

Only small particles reach the omasum, the third stomach. Many are recycled and absorbed as nutrients.

INSIDE THE OMASUM



Filter inside the omasum



RUMEN BACTERIA
The rumen creates an environment appropriate for the growth and reproduction of microbes. The absence of oxygen inside it favors the growth of bacteria that can digest plant cell walls to produce simple sugars (glucose). Microbes ferment glucose and provide energy to grow and produce volatile fatty acids as the final product of fermentation.

4

The abomasum secretes strong acids and digestive enzymes that finish breaking down the food bolus (the mass of chewed food).

5

As they grow, microbes in the rumen produce amino acids, the building blocks of proteins. Bacteria can make use of ammonia or urea as sources of nitrogen to produce amino acids. Without bacterial transformation, ammonia and urea would be of no use to cows.

30%
OF THE ENERGY FROM CONSUMED FOOD IS USED FOR DIGESTION.

6

After the main process of digestion and absorption of nutrients, what remains continues through the small and large intestines. There the remaining digestive products ferment, and wastes, or feces, are formed.

8 HOURS OF RUMINATION DAILY

THE RUMINATION PROCESS

helps ruminants reduce the size of the ingested food particles. It is part of the process that allows them to obtain energy from plant cell walls, also called fiber.

A REGURGITATION → B REMASTICATION → C REINSALIVATION → D REINGESTION

The Great Chain

Maintaining ecological balance requires the existence of prey and predators. Predatorial species bring about a sustained reduction in the number of individuals of the prey species. If predators did not exist, their prey would probably proliferate until the ecosystem collapsed, because there would not be enough food for them all. Disappearance of predators is the cause of many imbalances created in certain habitats by people, whose predatory ability exceeds that of any other living species. Like all other animal species, mammals do not make up a food chain in themselves, instead depending at all times on the participation of plants and other animals.

Level 4

Large carnivores are at the top of the food chain—there are no other predatory species that regulate their population.

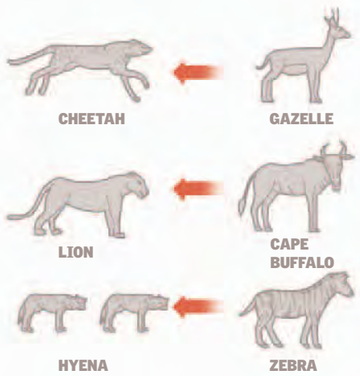
SMALL-SPOTTED GENET
Like many highly predatory large felines and dogs, it is in danger of extinction as a result of human activity.

WOLF
eats prey that it catches but can also compete with scavenger birds.

GEOFFROY'S CAT
likes to hunt larger animals (such as deer).

Kings of the Jungle

Lions are great carnivores (one of the largest in size) and strong, with little or no competition. Cheetahs will rapidly flee from lions if the latter arrive to challenge them for their food. Only when a lion is alone might a pack of hyenas, for example, confront it to steal its meal.



Level 3

Small carnivores feed on small, herbivorous mammals or on birds, fish, or invertebrates. At the same time, they must be on guard against other, larger species.

Small Omnivores
Ferrets feed on birds and amphibians, as well as on other mammals, such as rats, mice, and moles. They also eat fruit.

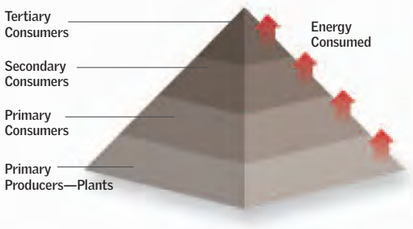
Not Only Mammals
Ferrets are important in controlling rodents, but they must simultaneously guard against birds of prey.

Equilibrium of the System

There is a very efficient natural equilibrium in the food chains of a terrestrial ecosystem, of which mammals form various parts. For this balance to be maintained, there can never be more herbivores than plant food or enough carnivores to overwhelm the herbivores. If there were more herbivores than plant food, they would eat all the vegetation and then suffer a drastic population reduction. A similar situation would occur if there were enough carnivores to overwhelm the herbivores.

Trophic Pyramid

Energy is transferred from one level to another in an ecosystem. At each level, a small amount of energy is lost. What is retained at one level is the potential energy that will be used by the next. Biomass is the total mass of living matter; it can apply to a specific level of the trophic pyramid, a population of individuals of the same species, or a community of different species.



Population

IS GREATER AS ONE GOES DOWN THE PYRAMID.

Level 2

Primary consumers devour autotrophic organisms (plants or algae), because they depend on them for subsistence. And other mammals feed on them.

Competition
Within the same level, different herbivorous rodents (such as rats and prairie dogs) compete with each other for food.

Super-adapted
Because of their highly varied plant diet, these rodents usually have no problem surviving.

A FOOD CHAIN CAN REACH SEVEN LEVELS.

Varied Diets
There are species that have another species as their sole food; but, in general, the chain branches out.

Level 1

Because of photosynthesis, only plants and algae can transform inorganic matter into organic matter. They form the beginning of the food chain.

Scavengers

eat meat from animals that are already dead. Some carnivores become scavengers under conditions of scarcity.

One for All

Meerkats are small mammals that live in underground colonies, posting guards while the mothers take care of their young. During the day they go above ground to feed, and at night they go into the burrow to take refuge from the cold. In this large family, made up of dozens of members, each one fulfills a function. When faced with danger, they employ various tactics to defend themselves. One of these is the squeal that lookouts emit in the face of even slight dangers.

MEERKAT
Suricata suricatta

Family	Herpestidae
Habitat	Africa
Offspring	2 to 7

12 inches (30 cm)

Weight 2 pounds (1 kg)

ABOUT 30 IS THE NUMBER OF INDIVIDUALS A GROUP CAN HAVE.

Social Structure

The social structure is extensive and well defined, ensuring that everyone has a role to fulfill. The lookouts (which may be female or male) take turns to sound the alarm over the arrival of strangers; one that is better fed replaces another that needs to eat. These animals are carnivorous. They eat small mammals, as well as insects and spiders.

BLACK-BACKED JACKAL
The meerkats' largest predator. To detect one before it is seen is of prime importance for the colony.

FEMALES
must dedicate all their energy to the process of reproducing and feeding and raising young.

OFFSPRING
When the father or mother standing watch gives the cry of danger, all run to hide in the burrow.

MALES
defend their territory and stand watch. The dominant male is the reproducer.

Territory

The area defended provides the food necessary for the group's subsistence. Males devote themselves to defense, and when resources run out the group migrates to another area.

BURROWS
They dig them with their sharp claws and leave them only during the day.

MARTIAL EAGLES
The most dangerous enemy they have and the one that kills the greatest number of meerkats

Defense

1 SURROUNDING THE ENEMY
They emit a type of squeal. They rock back and forth. They try to appear larger and more ferocious than they are.

2 ON THEIR BACKS
If this tactic fails, they throw themselves down on their backs to protect their necks, showing their fangs and claws.

3 PROTECTION
When it is an aerial predator, they run to hide. If taken by surprise, adults protect the young.

Lookout

When a predator is detected, the lookout warns its group so that all of them can take cover in a nearby hole. This role rotates among different members of the group, and the warning is given by a very wide repertoire of sounds, each of which has a distinct meaning.

SIGHT
Binocular and in color, it allows them to locate their greatest predators, birds of prey.

HEAD
is kept permanently erect, observing the burrow's surroundings.

MEERKATS ALSO USE VOCALIZATIONS TO COMMUNICATE.

VIGILANCE FROM ABOVE
It is common to see them in the highest places of their territory on **rocks or tree branches.**

FRONT PAWS
They have strong claws, which they use for digging or to defend themselves.

HIND FEET
They support themselves on their hind feet when they remain standing, keeping watch.

TRIPOD TAIL
Meerkats use it to balance themselves when they are in an upright position.

Wolves in Society

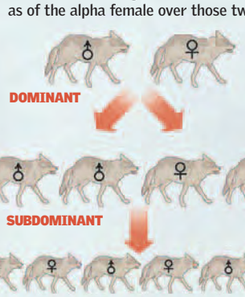
Social units and mutual aid are common in mammals' lives, except for a few species that live alone or in small families. Wolves are social animals that live closely attached to a group—the pack—that forms the basis of their social structure. Behavior in a pack is highly regulated and hierarchical.

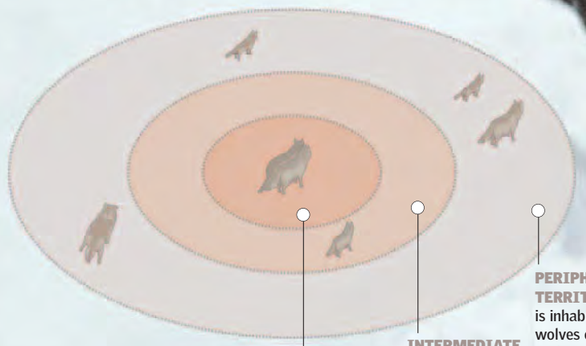
VOCAL COMMUNICATION plays an important role, allowing wolves to locate pack members.

GAMES
Although it looks like the wolves are playing in this picture, they are actually carrying out a game involving power and hierarchy.

Hierarchy

There are two hierarchies in the pack: one of males and another of females. At the top of each are the alpha (or dominant) male and female. Underneath this pair is a group of subdominant wolves among whom there may be little or no difference in rank. Among females, a strong dominant-submissive relationship is observed between beta and gamma wolves, as well as of the alpha female over those two.





TERRITORY
The highest-ranking adults live in the central area or home. The territory proper lies in the periphery and is inhabited by subadults and members of lower social rank. Between these two areas is that of vital domain, an intermediate area inhabited by all members. The territory can extend over 100 square miles (300 square km).

CENTRAL AREA is inhabited by the highest-ranking animals.

INTERMEDIATE REGION is inhabited indiscriminately by all the wolves.

PERIPHERY, OR TERRITORY is inhabited by wolves of lower social rank.

DOMINATORS
Made up of the breeding pair, which is dominant, and their descendants. Only the breeding pair, however, are permanently dominant. A relationship of dominance-submission between sexes is also established. The alpha female exercises clear dominance over the subdominant males.

DOMINANT PAIR

LEGS IN THE AIR
This posture implies submission and nonaggression.

Recognition of Position

Fights and confrontations within the pack are rituals by means of which relations of power and hierarchical status are established and delimited.

1 Encounter

The low-ranking wolf advances with submissive posture: ears laid back and its tail between its legs.

2 Examination

It crouches in front of the snout of the dominant and gives it rapid licks, submitting to the hierarchy.

3 Recognition

Then it lies down and urinates while the dominant smells its genitals to identify it.

6 to 20 individuals
IS THE SIZE OF THE PACK DEPENDING ON THE AVAILABILITY OF FOOD.

The Family

Wolves live in packs made up of two to three pairs of adults and their various generations of offspring. They cooperate in hunting, killing animals several times larger than themselves. Although they share food, wolves have a hierarchical order that obliges the young to make way for larger and older family members.

Diversity

DEEP SLEEP 62-63
RATIONED WATER 64-65
RECORD BREATH-HOLDERS 66-67
AERIAL ACROBATICS 68-69
NATURAL BUILDERS 70-71
NOCTURNAL FLIGHT 72-73
PLAYING HIDE AND SEEK 74-75
THE LANGUAGE OF WATER 76-77
LIVELY TUNNELS 78-79

DISTINCTIVE STRIPES
Zebras' stripes extend down to the underbelly. They confuse predators.

There is great variety among mammals, and in this chapter we try to show you some representatives of the most outstanding differences among them. For example, here you will discover that there are species, such as bats, that are expert fliers, while others, such as dormice, enter into a deep winter sleep that allows them to save energy during times when food is scarce. Here we will also show you how the bodies of some mammals (whales and dolphins) are adapted to aquatic life. In addition, we will also consider the ability of certain mammals to adapt to the hot and dry conditions of the desert. Camels, in particular, are very adept when it comes to retaining and efficiently using liquids. ●

Deep Sleep

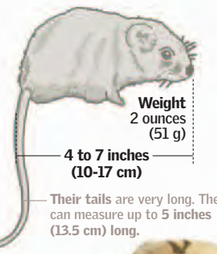
How many times have you heard the expression "dead as a dormouse"? The comparison is no accident, although it should be understood that dormice do not die: they merely hibernate. In the cold season, low temperatures and scarcity of food lead many mammals to enter into lethargic states. Body temperatures drop, heart rates and respiration slow down, and they lose consciousness.

HAZEL DORMOUSE
Muscardinus avellanarius

Habitat	**Almost all Europe**
Habits	**Hibernate 4 months of the year**
Gestation	**22 to 28 days**

When Active

The energy they consume during hibernation is obtained from the subcutaneous fat layer built up during the autumn. Their nutrition comes from leaves, bark, nuts, and other (mainly plant) foods. Before the arrival of winter, they stock up on dried fruits to increase their energy, allowing them to easily climb trees and walls. Before hibernating, they spend all their time eating, accumulating reserves for winter.



Weight
2 ounces (51 g)

4 to 7 inches (10-17 cm)

Their tails are very long. They can measure up to **5 inches (13.5 cm) long.**

95°F (35°C)
THEIR NORMAL BODY TEMPERATURE.

NUTS
Although they consume snails and insects, dormice begin to feed on nuts prior to hibernation.

ACORNS
The nuts of oak trees (genus *Quercus*) are a favorite food of dormice.

CHESTNUT
Its caloric contribution increases their energy reserves.

LEAVES OF THE OAK TREES
Dormice are very fond of oak trees.

11 ounces (300 g)
is what they can weigh after accumulating fat reserves before hibernating.

Building the Nest

Dormice build their nests out of twigs, moss, and leaves, although they can also hibernate in trees, stone walls, or old buildings, creating a nest from fur, feathers, and leaves. They then settle into the nest, forming a ball. When they cannot find a natural refuge, dormice may settle into birds' nests with total impunity.

1 RAW MATERIALS
To build their nests, dormice collect twigs, leaves, moss, feathers, and hair.

2 BALL
Dormice begin to form a ball out of these materials, in imitation of the posture they will adopt during hibernation.

3 HOLLOW BALL
Like an ovenbird nest, the ball must be hollow so it can shelter the dormouse.

4 FINISHED NEST
With an entrance in front, the hollow ball has been transformed into a nest.

50%
Weight loss after consuming all their reserves

Hibernation

During this period, dormice enter into a deep sleep. Body temperature drops to 34° F (1° C), appreciably decreasing the heart rate. In fact, up to 50 minutes can transpire between breaths. Throughout these months, they slowly use up their reserves, losing up to 50 percent of their body weight. Their endocrine system is almost totally at rest: the thyroid ceases functioning, as does the interstitial tissue of the testicles.

34°F (1°C)
THEIR BODY TEMPERATURE DURING HIBERNATION

November

December

February

March

8 months
They are conscious and active.

4 months
They remain in a state of hibernation.

POSITION OF THE BODY

TAIL
They cover part of the body with it.

HEAD
They hide it behind their long tail.

FEET
remain flexed during these months.

RESPIRATION
Fifty minutes can pass between breaths.

ENERGY
They obtain it from the subcutaneous fat reserves they accumulated in the fall.

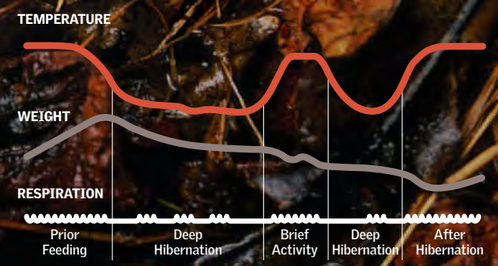
HEART
Heartbeats decrease considerably.

OTHER PLACES FOR HIBERNATION

BIRD'S NEST
If they do not find a place to build their nest, they may take over a bird's nest.

HOLE IN A TREE
can also serve as a burrow for hibernation.

BIORHYTHM OF A DORMOUSE WHILE HIBERNATING



Rationed Water

Camels have developed a sophisticated physiology in order to face life in hot climates. Their kidneys are capable of greatly distilling their urine to prevent water loss. When sandstorms worsen, camels curl up on the ground and close their eyes and nasal openings to protect themselves. When water and food are scarce, they are able to endure by consuming the reserves they have accumulated and stored in the hump and internal sacs. They also have oval-shaped red blood cells, which can easily move throughout the body even when the blood has become thickened from dehydration.

DROMEDARY, OR ARABIAN, CAMEL
Camelus dromedarius

Habitat	Arabia and Africa
Food	Herbivorous
Average life span	50 years

Characteristics

BODY TEMPERATURE
During the day, their bodies act as heat retainers, and during the night, the excess temperature dissipates by conduction.

NOSE
Their mucus structure is 100 times more complex than that of humans and retains 66 percent of the air's moisture.

HAIR
is so thick that it prevents heat from reaching the skin. When cold is intense, the hair keeps the camel warm with its own body heat.

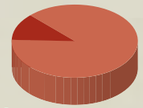
The Hump as a Reserve

Formed by the accumulation of fat during periods of abundant food, the hump is an energy reserve that dromedaries use in the absence of plant foods. This chemical reaction provides camels with a small but invaluable amount of metabolic water. The breakdown of the fat produces hydrogen, which combines with inhaled oxygen to produce water. By combining metabolic and cellular water, interstitial lymph, and plasma, they can go without food and water for long periods of time.

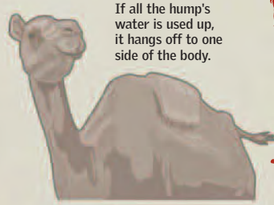
34 gallons (130 l)
THE AMOUNT OF WATER DROMEDARIES CAN CONSUME IN 10 MINUTES

RESISTANCE TO THIRST AND HUNGER

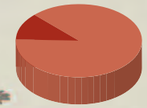
Dromedaries can go without food and water for **eight days** at a temperature of **122º F (50º C)**.



12% The maximum percentage of body weight a person can lose without dying



If all the hump's water is used up, it hangs off to one side of the body.



40% The maximum percentage of body weight camels can lose without dying

HUMP
Fat accumulates and prevents the excretion of water from the whole body. This allows camels to use a minimum of water.

31 pounds (14 kg)
HUMPS CAN WEIGHT THIS MUCH.

2 pounds (1 kg) of consumed fat = **2 quarts (2 l)** of metabolic water

Kidneys

greatly distill the urine, preventing unnecessary water loss. The urine may get as thick as syrup and contain double the salt of seawater. In this way, camels eliminate impurities and filter the blood, losing as little water as possible.

LOOP OF HENLE
recovers part of the water. Because the loop is longer in dromedaries than in any other mammal, water circulates for a very long time.

KIDNEYS
concentrate urine to retain water.

ERYTHROCYTES

240%
The percentage by which an erythrocyte can swell, increasing its ability to transport water.

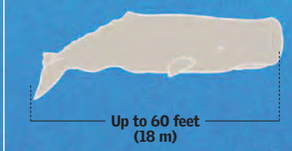
KNEES
have calluses so camels can kneel without getting burned.

Record Breath-Holders

Sperm whales are unique animals whose species is remarkable for many reasons. On the one hand, they have the ability to dive to a maximum depth of 9,800 feet (3,000 m) and remain underwater without oxygen for up to two hours. They are able to do this by means of a complex physiological mechanism that, for example, can decrease their heart rate, store and use air in the muscles, and prioritize the delivery of oxygen to certain vital organs such as the heart and lungs. They are the largest whales with teeth, which are found only on the lower mandible.

SPERM WHALE
Physeter catodon

Habitat	Deep waters
Status	Vulnerable
Sexual Maturity	18 years



Weight

20 to 90 tons

By Comparison

11 elephants of 8 tons apiece

Up to 120 minutes

IS THE LENGTH OF TIME THEY CAN SPEND UNDERWATER WITHOUT BREATHING.

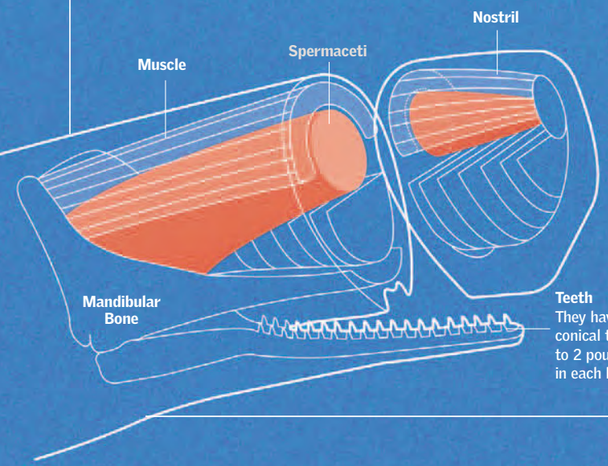
1 SPIRACLE
The sperm whale breathes oxygen into its body through spiracles located on the top of its head.

2 REPRIORITIZING OXYGEN
Sperm whales can allocate oxygen to certain vital organs, such as the lungs and heart, directing it away from the digestive system.

3 BRADYCARDIA
During a dive, the heart rate drops (a condition known as bradycardia), which lowers oxygen consumption.

TAIL
is large and horizontal and is the whale's main means of propulsion.

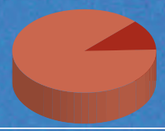
MOUTH
Because of the placement of the nostrils, sperm whales can swim with their mouth open and capture prey. They feed on squid.



Teeth
They have 18 to 20 conical teeth, weighing up to 2 pounds (1 kg) apiece, in each lower mandible.

Spermaceti Organ

Sperm whales' ability to dive to great depths could be due in part to their spermaceti organ, located in their heads. It consists of a large mass of waxy oil that helps them both float and take deep dives. Its density changes with temperature and pressure change. It, like the melon of a dolphin, directs sound, focusing clicks, since its eyes are of little use when far from light.



COMPOSITION

90% Spermaceti Oil
It is made up of esters and triglycerides.

Adaptation in Respiration

When they dive to great depths, sperm whales activate an entire physiological mechanism that makes maximum use of their oxygen reserves. This produces what is called a thoracic and pulmonary collapse, causing air to pass from the lungs to the trachea, reducing the absorption of the toxin nitrogen. They also rapidly transmit nitrogen from the blood to the lungs at the end of the dive, thus reducing the circulation of blood to the muscles. Sperm whales' muscles contain a large amount of myoglobin, a protein that stores oxygen, allowing the whales to stay underwater much longer.

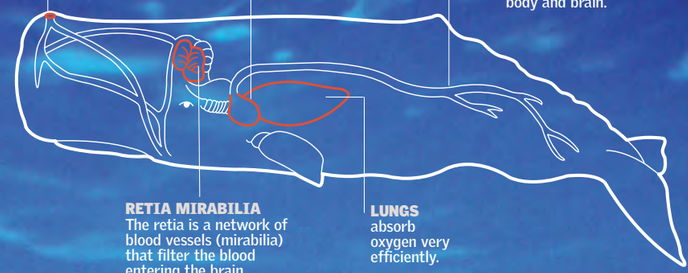
ON THE SURFACE
Blowhole remains open, allowing the whales to breathe as much oxygen as they can before diving.

WHEN THEY DIVE
powerful muscles tightly close the opening of the blowhole, keeping water from entering.

BLOWHOLE
Upon submerging, it fills with water, which cools the spermaceti oil and makes it denser.

HEART
The heart rate slows down during the dive, limiting oxygen consumption.

BLOOD
An ample blood flow, rich in hemoglobin, transports elevated levels of oxygen to the body and brain.



RETIA MIRABILIA
The retia is a network of blood vessels (mirabilia) that filter the blood entering the brain.

LUNGS
absorb oxygen very efficiently.

Making Use of Oxygen

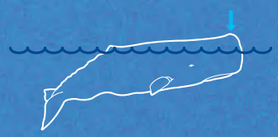
Sperm whales can dive deeper and stay submerged longer than any other mammal, because they have various ways of saving oxygen: an ability to store it in their muscles, a metabolism that can function anaerobically, and the inducement of bradycardia during a dive.

15%
AMOUNT OF AIR REPLACED IN ONE BREATH

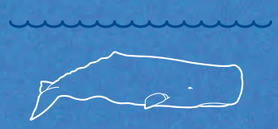
85%
AMOUNT OF AIR REPLACED IN ONE BREATH

Dive

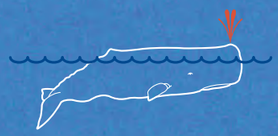
True diving champions, sperm whales can dive to depths of 9,800 feet (3,000 m), descending up to 10 feet (3 m) per second in search of squid. As a general rule, their dives last about 50 minutes, but they can remain underwater up to two hours. Before beginning a deep dive, they lift their caudal fin completely out of the water. They do not have a dorsal fin, but they do have a few triangular humps on the posterior part of their body.



0 FEET (0 M)
ON THE SURFACE
They inhale oxygen through the blowhole located at the top of the head.



+ 3,300 FEET (1,000 M)
90 MINUTES
They store 90 percent of their oxygen in their muscles, so they can be submerged for a long time.



0 FEET (0 M)
ON THE SURFACE
They exhale all the air from their lungs; this is called spouting, or blowing.

Aerial Acrobatics

Cats have a surprising ability to land upright. The secret lies in their skeleton, which is more flexible and has more bones than that of any other mammal. Cats' reflexes allow them to twist using the physical principle of the conservation of angular momentum. The principle, first formulated by Isaac Newton, states that all bodies in circular movement tend to a constant amount of energy. Thus, the more the animal extends its legs to its axis of rotation, the slower it rotates, redistributing the total energy of the system. If the animal tucks in its legs, it rotates more rapidly. ●

Name	Domestic cat
Family	Felidae
Species	*Felis catus*
Adult Weight	4 to 15 pounds (2-7 kg)
Longevity	15 years

Dimensions

FORCE OF GRAVITY

AXIS

The "Accelerator"
The cat folds its front legs in to its axis to increase the speed of rotation of this part. It rotates 180°.

The "Brake"
It extends its hind legs perpendicular to the axis and reduces the speed of rotation of this part.

It draws its hind legs in to the axis of the body.

It extends its front legs at right angles to the axis.

Front Half
The extended legs reduce the speed of rotation of this part. It rotates 180°.

Back Half
Now the folded legs increase the speed of rotation of this part.

The tail stabilizes the weight of the body during the descent.

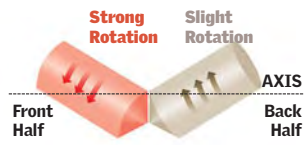
It extends the hind legs to the height of the front legs.

1 STARTS UPSIDE DOWN

The cat begins to fall upside down and will turn 180º upon its axis (in two stages), landing upright.

2 FIRST TWIST

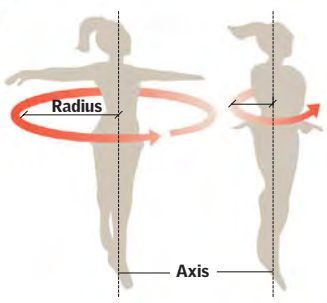
In this maneuver, the cat rotates the front half of its body 180º on its body's axis. The other half rotates only slightly as a result.



3 WITH INDEPENDENCE

Like a skater who extends or folds the arms to control the speed of rotation, the cat moves its hind legs—but independently of each other.

LIKE A SKATER

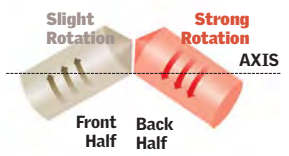


To reduce rotation
opens arms to increase the radius of rotation.

To increase rotation
closes arms to reduce the radius of the rotation.

4 SECOND TWIST

The cat lowers its hind legs and completes a full rotation on its axis. It again carries out two more rotations, one tighter than the other:



5 FOUR FEET PLACED UNDER THE BODY

With four feet positioned under the body, the cat bends its spine like a parachute and then merely corrects its posture for landing.

11% ELONGATION CAPACITY

Extreme Flexibility
Cats do not have a clavicle, and the articulations of their vertebrae are more flexible than those of most mammals. They can travel five times the length of their body in one leap.

1/8 of a second

TIME IT TAKES TO ROTATE AND LAND ON ITS FEET 1/2 SECOND LATER

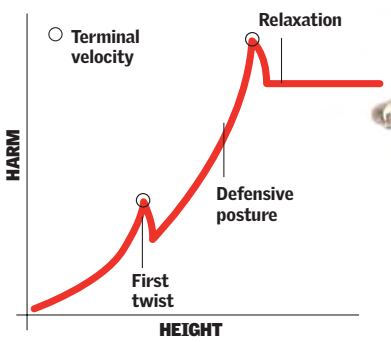
6 LANDING

Its front legs make the first contact with the ground. Then it lands on its hind legs, and, finally, it relaxes its tail.

At the moment of landing, the cat slightly flexes its feet to cushion the blow.

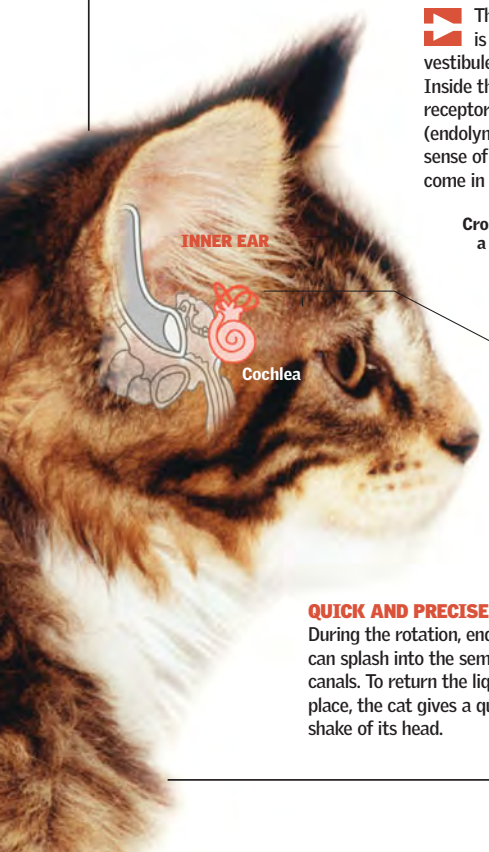
Time of the Fall

A fall from a short distance usually causes more harm than one from a considerable height, because the cat adopts a defensive posture only when it senses acceleration in the fall. Upon reaching terminal velocity, it can accelerate no faster, and the cat relaxes, stretches out, and offers resistance to the fall.



Equilibrium

The inner ear in the temporal bone is divided into the cochlea, the vestibule, and three semicircular canals. Inside there is a system of cilia (sense receptors) and a viscous substance (endolymph) that generates the sense of balance when the two come in contact with each other.



Cross section of a semicircular canal

Bulla
It holds the cilia, which are equilibrium receptors.

During a rotation, endolymph moves the cilia in the direction opposite the body's motion.

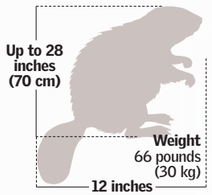
QUICK AND PRECISE SHAKE
During the rotation, endolymph can splash into the semicircular canals. To return the liquid to its place, the cat gives a quick shake of its head.

Natural Builders

They have no bricks or cement, but beavers, semiaquatic rodents, skillfully manage to build lodges of great architectural beauty. They do not work alone, and it is usual for them to act in family groups. Everyone collaborates in building the home, which is generally located next to a river or lake surrounded by forested areas and which can be entered only through aquatic tunnels. The task is difficult, and beavers work their whole lives enlarging, repairing, and improving their dwelling. ●

AMERICAN BEAVER
Castor canadensis

Habitat	**Temperate forests in the United States and Canada**
Family	**Castoridae**
Food	**Herbivorous**



ENVIRONMENTAL IMPACT

Beavers can have positive and negative effects. They create wetlands for other species and prevent erosion in some cases. However, their dams can also cause floods and create stagnant water, thus destroying other habitats.

The Lodge

These are unique structures, of which there are several types, which vary by area. They are made of interwoven sticks, branches, grasses, and moss, and they have a central chamber accessible from underwater. This chamber has its floor above the water line, has two entrances, and can measure more than 7 feet (2 m) wide and 3 feet (1 m) high.

OFFSPRING
live with their parents and are independent after three years.

DRY AREA
Covered with tree bark, grass, and little pieces of wood

CHANGES
Their introduction into new environments may change the ecological balance so much that they become a pest.

UNDERWATER TUNNEL
They move secretly through underwater tunnels, generally remaining underwater for five minutes.

ENTRANCE
Here is where they enter; it is a straight path at an incline.

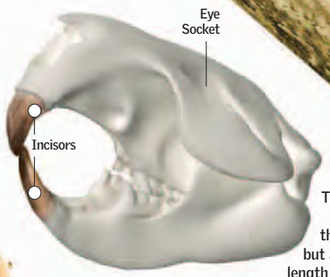
EXIT
Beavers have webbed feet that they use to dive and for other quick movements.

THE FOUNDATION
In winter, they store fresh branches in the pond to serve as a food reserve.

BRANCHES
The material most used in constructing the lodge. They are used to make the ceiling and to keep the inside dry.

TEETH

Their powerful incisors grow throughout their lives but are kept at manageable length by wear and tear from the constant work of cutting down trees.

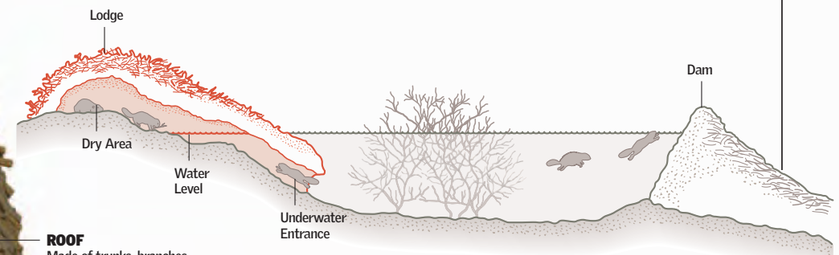


2 times
THE STRENGTH OF THEIR INCISOR TEETH (USED FOR CHEWING) IN COMPARISON WITH HUMANS

15 minutes
IS HOW LONG A BEAVER CAN STAY UNDERWATER WHEN THREATENED.

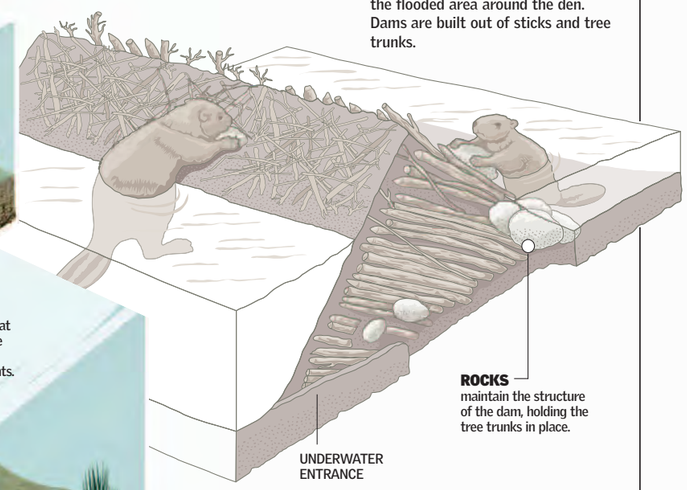
Dam

Beavers continually repair the dam and add materials to it. Floating material carried along by the water is retained in the dam, along with the roots of vegetation that grows upon it, strengthening the entire structure.



ROOF
Made of trunks, branches, stones, and mud. In this way they form a small lake where they build their hut.

THE DAM
has two purposes—first, to raise the water level; and second, to enlarge the flooded area around the den. Dams are built out of sticks and tree trunks.



TECHNIQUES

Beavers frequently work in groups to gnaw down a trunk and carry it away. One of them cuts the tree with its teeth while the others stand guard. This work takes about 15 minutes, and then the tree falls.

Their mandibles and teeth are strong, and they use their front feet as hands.

Nocturnal Flight

Bats are the only mammals that can fly. Scientists call them Chiroptera, a term derived from Greek words meaning "winged hands." Their forelimbs have been transformed into hands with very long fingers joined together by a membrane (called the patagium) that forms the surface of the wing. These mammals' senses are so sensitive that they can move and hunt quickly and accurately in the dark.

60 miles per hour (97 km) THE SPEED SOME BATS MAY REACH DURING FLIGHT

Hibernation

These bats spend the winter in a lethargic state hanging by their feet, faces down, in caves and other dark places. Bats are warm-blooded animals while they are active and become similar to cold-blooded creatures when they are asleep. They enter into a state of hibernation more rapidly and easily than any other mammal, and they can survive in cold temperatures for many months—even inside refrigerators—without needing to feed.

FRUIT BAT (FRANQUET'S EPAULETTED BAT)
Epomops franqueti

Habitat	Forests of Ghana and Congo
Family	Pteropodae
Length of wingspan	14 inches (36 cm)

HUMERUS
RADIUS
THUMB
SECOND FINGER
FOURTH FINGER
THIRD FINGER
PATAGIUM

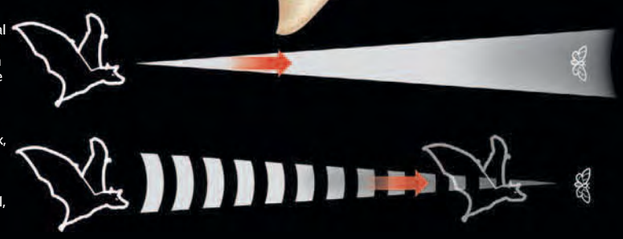
Expert Pilots

Moved by their chest and back muscles, bats' wings push downward and backward, generating both thrust and lift. Then the wings spread sideways and upward. Finally they move forward until the tips almost rub the bat's head. Many of these flying mammals can drift through the air, gliding without flapping and maneuvering by folding their wings.

Their Radar

Most of the time bats fly at night in near-total darkness. Instead of light, they use a natural system similar to sonar or radar to guide themselves. This system makes use of acoustical signals the bats themselves emit while flying. This system allows them to recognize the location of any object in front of them or of prey, along with its direction, size, or speed. It is as if they were seeing without light.

1. The animal emits an acoustical vibration imperceptible to the human ear because of its high frequency (about 18 kHz). The signal strikes the objects around it.
2. When the signals bounce back, the bat perceives their intensity and phase difference—the faster and more intense the return signal, the nearer the object or prey.



HAND OR WING
The first finger, or thumb, has no membrane and is used as a claw. Powerful muscles move the entire wing.

UROPATAGIUM

ELASTIC FIBERS
The texture of the wing is soft and flexible. It is lined with blood vessels.

Flexible Wings

The patagium is formed by the membranes between the digits. In some species, the wings are also extended by an additional membrane (uropatagium), which joins the hind limbs to the tail. Their wings are not only used for flying (pushing the air as if they were oars in water) but also help to maintain a constant body temperature and to trap insects, upon which bats feed.

Playing Hide and Seek

Just like other species of the animal kingdom, some mammals that live in the wild rely on their bodies' colorations or appearances to disguise their presence. Some mammals imitate objects in their environment, and others take on the appearances of other animals. Zebras' stripes, for example, give these animals a very showy appearance—but when moving in their natural environment, zebras are camouflaged. Some differentiate between mimicry and crypsis, which is the natural ability to go unnoticed without requiring any associated behavior. In other cases, however, the forms and colors of camouflage would be useless if they were not accompanied by some kind of imitative behavior. An animal cannot improve its camouflage, but it can improve its mimicry.

Evolutionary Adaptations

Mimicry is defined as the ability of some living beings to imitate the appearance of another living being or an inanimate object in the environment. Protective mimicry is the camouflage used by animals incapable of defending themselves in any other way. Aggressive mimicry, on the other hand, allows organisms to surprise and attack their prey. This occurs, for example, with wild felines (mountain lions, ocelots, lynxes), which take advantage of their skin colors and the patterns of their fur to go unnoticed in their ecosystems. Zebras travel in herds as a natural form of self-protection. The disruptive coloration of their coats makes it difficult for predators that rely on speed and sharp senses to distinguish one individual prey from another. Kicking and biting, zebras collectively defend themselves from attacks by feline predators. These felines also make use of camouflage strategies to make their attacks one on one. Many animals make use of elements from their surroundings or even of other living organisms to camouflage themselves. Sloths are another example; being the slowest of the mammals, they have no choice but to cover themselves in algae to avoid notice.

STRIPES
The coloration of their coat changes with the incidence and intensity of sunlight.

SPOTS
allow giraffes to conceal themselves among the high leaves they reach with their long neck.

PATTERNS
are irregular forms between stripes that allow tigers to lie in ambush for their prey among thickets.

Different Patterns

The pattern of a zebra's coat does not exactly copy the shapes and colors of objects in the wild environment surrounding it. Nevertheless, it does have patterns that allow it, with the help of certain behaviors and motions, to disguise its appearance in more than one setting of the zebra's natural habitat. In the case of Arctic animals, it is the uniform white color of the winter environment that determines the way in which species camouflage themselves.

In Motion

The patterns of tigers' coats are useful in concealing their contours, especially when they are moving among the shrubs and bushes of the plains where they hunt. Elk horns, however, can be concealed among the vegetation they resemble only so long as they keep still.

Disruptive Coloration

The body's contours are blurred when some spots of color are much darker or lighter than the rest of the coat.

Part of the Hideaway

Chipmunks (*Tamias* species) live in coniferous or deciduous forests, where they feed on nuts, insects, eggs, seeds, and other plant foods. The colors of their coats are essential, because—although they are very skillful at moving in the upper branches—their small size and short legs make them very vulnerable when they are on the ground.

PROTECTIVE SURROUNDINGS
Many have a coat that changes color depending on the surroundings.

FUR
Shades and differences of color in the coat are similar to those of tree trunks and dry leaves.

The Language of Water

The ways in which cetaceans communicate with others of their kind are among the most sophisticated in the animal kingdom. Dolphins, for example, click with their mandibles when in trouble and whistle repeatedly when afraid or excited. During courtship and mating, they touch and caress. They also communicate through visual signals—such as leaping—to show that food is close by. They have a wide variety of ways to transmit important information.

HAVING FUN
Play for dolphins, as with other mammals, fulfills an essential role in the formation of social strata.

Common Name	Bottlenose dolphin
Family	Delphinidae
Species	*Tursiops truncatus*
Adult Weight	330 to 1,400 pounds (150 to 650 kg)
Longevity	30 to 40 years

7 to 13 feet (2-4 m)

They reach **22 mph (35 km/h)**

MELON
is an organ filled with low-density lipids that concentrate and direct the pulses emitted, sending waves forward. The shape of the melon can be varied to better focus the sounds.

SPIRACLE

LIP

NASAL AIR SAC

DORSAL FIN
allows dolphins to maintain their equilibrium in the water.

LARYNX

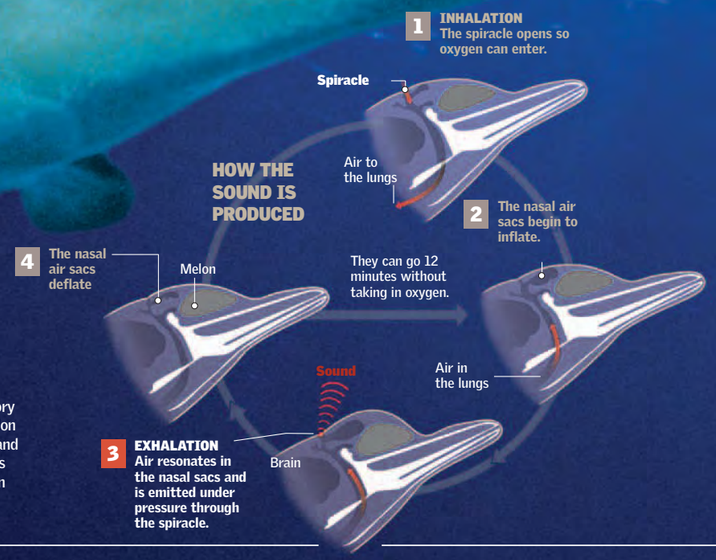
CAUDAL FIN
has a horizontal axis (unlike that of fish), which serves to propel dolphins forward.

PECTORAL FIN

1 Emission

Sounds are generated by air passing through the respiratory chambers. But it is in the melon that resonance is generated and amplified. Greater frequencies and intensities are achieved in this way.

HOW THE SOUND IS PRODUCED



MANDIBLE
The lower mandible plays a very important role in the transmission of sounds to the inner ear.

2 Message

Low-frequency signals are used for communication with other dolphins, and high-frequency signals are used as sonar.

1 mile per second (1.5 km/s)

SOUND WAVES TRAVEL 4.5 TIMES FASTER IN WATER THAN IN AIR.

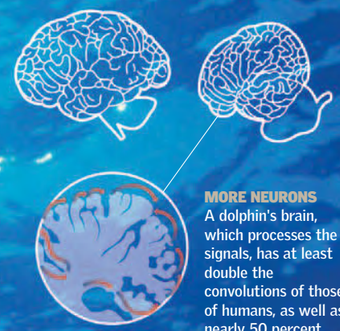
3 Reception and Interpretation

The middle ear sends the message to the brain. Dolphins hear frequencies from 100 Hz up to 150 kHz (the human ear can hear only up to 15 kHz). Low-frequency signals (whistles, snores, grunts, clinking) are key in the social life of dolphins, cetaceans that cannot live alone.

MIDDLE EAR

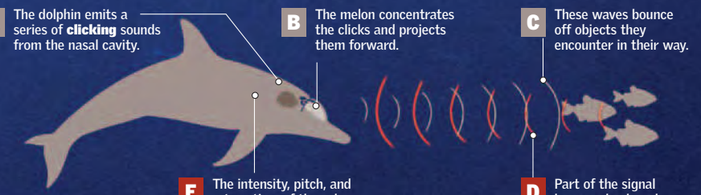
3 pounds (1.4 kg) **HUMAN BRAIN**

4 pounds (1.7 kg) **DOLPHIN BRAIN**

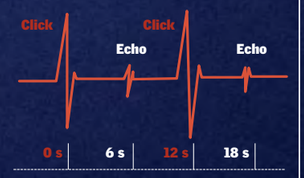


MORE NEURONS
A dolphin's brain, which processes the signals, has at least double the convolutions of those of humans, as well as nearly 50 percent more neurons.

Echolocation



SIGNAL WITH ECHO



Lively Tunnels

Rabbits are gregarious animals that live in colonies in a series of burrows called warrens. The burrows are dug underground and are inhabited by females of high social rank. Rabbits are principally nocturnal and spend most of the day hidden in the burrow, leaving to eat when night falls.

PREFERRED PLACES
The area around the burrow needs two things before the rabbits will feel comfortable—grass and cover. Generally rabbits build warrens in meadows near thickets or rocks.

200 feet (60 m)
IS THE FARTHEST A RABBIT WILL WILLINGLY GO FROM ITS BURROW.

RABBIT FOOTPRINTS
Their footprints are unmistakable, the result of their peculiar way of walking and jumping.

HIND FOOT

Danger Print — Normal Footprint

DANGER SIGNAL
In the presence of strangers or in other cases of danger, rabbits thump the ground with the back part of their hind feet, warning the others not to leave the burrow.

SONIC ALERT
When they thump, rabbits produce a sound that all the rabbits in the colony hear. If a rabbit is trapped, it will emit a sharp squeal that can be heard throughout the area.

Rabbits that receive the warning will remain in place, motionless.

ENTRANCE TO THE WARREN
6 inches (15 cm)

Warren
This is the main part of the burrow, where the adult rabbits live. It is made up of a complex network of interconnected corridors and chambers.

MOUNDS
FOOD DEPOSIT
NEST

5 to 8 inches (12-20 cm)
FOOD CELLARS

3 to 10 feet (1 to 3 m)
LIVING AREAS

PROTECTED INTERIOR
Interior tunnels are lined with vegetation and rabbit fur to keep them from deteriorating and to protect them from moisture.

1 Front Feet
When it jumps, it first lands on its front feet, which are bunched together.

Both feet leave almost a single footprint, small and not very distinct.

This gives rabbit footprints their peculiar Y-shaped appearance.

RABBIT FOOTPRINT PATTERNS
They always follow this Y pattern.

Walking Rabbit — Jumping Rabbit

2 Hind Feet
Then it lets its hind feet land in front of its front feet.

Front Feet — Hind Feet

3 New Hop
It begins the cycle again by pushing off with the hind feet.

SECONDARY ENTRANCE

DIET
They feed on herbaceous and grassy plants, roots, and bulbs. Some of their excrement is soft, covered with mucus, and is re-ingested, the equivalent of bovine rumination.

Secondary corridors
are often smaller and not interconnected. The offspring of the younger females live there.

When the mother leaves her offspring she seals the entrance with dirt to protect them from danger.

The secondary corridor has only one exit, which is not connected to the warren or other areas.

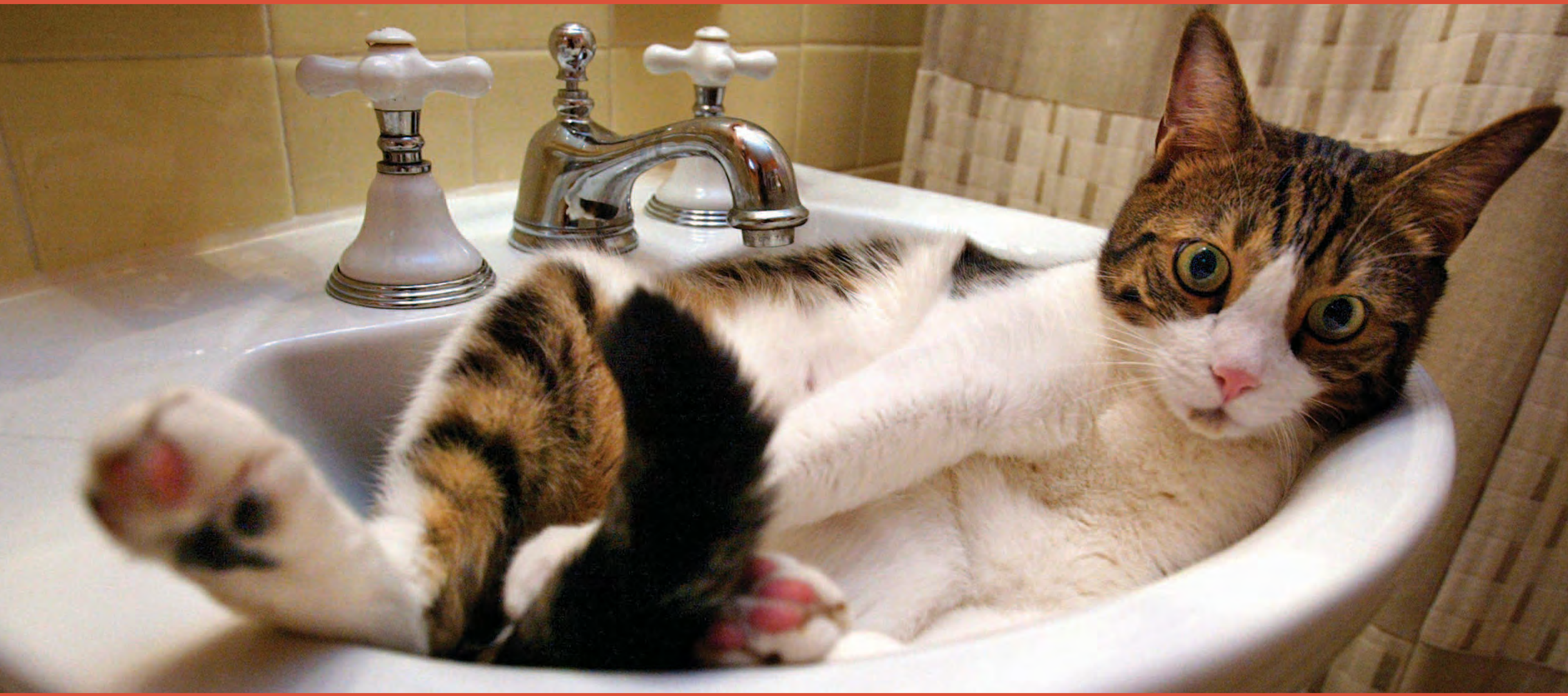
130 feet (40 m)
IS HOW LONG A BURROW TUNNEL CAN BE.

The young rabbit will grow in safety there until it is capable of fending for itself.

Relationship with People

LIKABLE AND PLAYFUL
Cats are excellent companion animals and are known for their great independence and cleanliness.

MYTHS AND LEGENDS 82-83
EACH IN ITS PLACE 84-85
RAISING HOGS 86-87
MILK PRODUCTION 88-89
THE HUMAN THREAT 90-91



The history of cats goes back 12 million years to the time when felines began to populate the Earth. However, their domestication began 4,000 years ago. The Egyptians decided to incorporate them into their home life, thus keeping rats away. Then the Phoenicians took them to Italy and the rest of Europe. One of the subjects discussed in this chapter has to do with the things that threaten the existence of many animal species, including the loss of natural habitats, poaching, pollution, and illegal pet trafficking. Within the next 30 years, almost one fourth of the Earth's mammals could disappear. ●

Myths and Legends

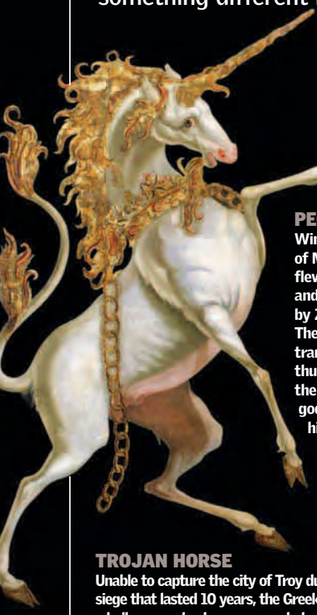
Human history has always been intimately linked with the various mammals—after all, people are mammals, too! Numerous myths and legends have arisen from this relationship, such as that of the wolf goddess Luperca, who saved Romulus and Remus from death—or the story of the birth of the Minotaur, in which a queen was caused to fall hopelessly in love with a bull and give birth to a monster with a bull's head and man's body. The origin of each myth springs from a particular tradition and means something different in each culture.

MINOTAUR
In Greek mythology, this was a creature born with the body of a man and the head of a bull that ate human flesh. It was born on the island of Crete of a forced sexual relationship between Pasiphae, wife of King Minos, and a white bull that Poseidon gave the king to use as a sacrifice.

East

In Eastern culture, animals, especially mammals, have played a leading role in myths and legends. Sometimes one animal has various meanings in various cultures. To Egyptians, cats represent harmony and happiness, but the Buddhist world disapproves of cats because they, along with snakes, were the only ones who did not cry at Buddha's death.

UNICORN
This stone seal depicting a unicorn is found in the National Museum of Pakistan in Karachi and dates from the year 2300 BC.



PEGASUS
Winged horse, son of Medusa, who flew to Olympus and was received by Zeus. Thereafter, he transported thunderbolts for the king of the gods, who placed his figure in the night sky.

Myths

THEIR ORIGIN STEMS FROM THE OBSERVATION OF NATURE.

ROMULUS AND REMUS
These two brothers were abandoned on the shores of the Tiber, but they were found by a female wolf, Luperca, who suckled and raised them. Later, as adults, they returned to the place where they had been abandoned and there founded Rome.

LION
The Manjusri Buddha, seated on the mythical lion who is the guardian of Buddhist doctrine

TROJAN HORSE
Unable to capture the city of Troy during a siege that lasted 10 years, the Greeks built a hollow wooden horse, concealed warriors inside it, and left it on the beach. The Trojans, thinking it a gift from Poseidon, brought it into the city. At night, the warriors left their hiding place and opened the city's gates to the remainder of the Greek army, burning and seizing the city.

West

In Western culture, the Greeks and Romans have been the great producers of myths and legends relating animals to humans. Human bodies with the heads of bulls or the limbs of horses are some of many examples.

CERBERUS
This was the monstrous, three-headed hound of Hades, or hellhound, which guarded the kingdom of the dead, preventing the dead from leaving and the living from entering.

CAT
Bastet, the Egyptian goddess who watched over the home. She symbolizes the joy of living and was represented as a woman with a cat's head, because her sacred animal was the cat.

Each in Its Place

Nature takes care of maintaining its equilibrium, providing each animal its own role within the food chain. When one of the roles is removed, equilibrium in the region is lost. In Australia, dingoes were a big problem for sheep farmers, who built a great fence to protect their flocks. This barrier left the wild dogs without prey and other species able to move about more freely in search of food. Dingoes are classified as pests both for farm animals as well as for rabies control.

The Introduction of the Dingo

It is thought that dingoes were domesticated animals of the Australian Aborigines who lived in the region. These mammals originated in Asia and were brought to Australia by humans. They are medium-sized wild dogs with thick tails and are notable for having a very distinctive howl instead of a bark. When European pioneers arrived in Australia, dingoes were accepted, but this rapidly changed when sheep became an important part of the economy. Dingoes were soon trapped, hunted, and poisoned.

CHAIN
Because of the building of the barrier, herbivorous animals have more space to graze, safe from the presence of dingoes.

DINGO
The leading predators of sheep, dingoes were isolated from the area.

SHEEP
Their population increased with the absence of the dingo.

KANGAROO
They found greater freedom to move about in search of food.

PASTURELANDS
became scarce, making it difficult for herbivores such as kangaroos and sheep to find food.

DINGO
Canis dingo

The Great Fence

was designed to keep dingoes out of the southeastern part of Australia, protecting flocks of sheep. It ran for thousands of miles and was largely successful in its objective. The number of dingoes in the area declined, and, although the loss of sheep to predators was reduced, this decline led to an ecological imbalance by increasing the competition for pastureland among rabbits and kangaroos.

3,300 miles (5,320 km)
THE LENGTH OF THE GREAT FENCE.

ORIGINAL COURSE
CURRENT COURSE
AREA FREE OF DINGOES

PERIMETER
Its shape changes according to its upkeep. The Australian government subsidizes the undertaking, but sheep farmers are the ones who maintain it.

Wool Industry

Australia is second in the world in wool production. It has 110 million sheep within its borders, constituting 10 percent of world wool production. In 1989, when part of the famous fence collapsed, about 20,000 sheep were lost to dingoes.

Raising Hogs

Hog farming is one of the oldest forms of livestock production. In fact, the biggest hog producers, the Chinese, began raising hogs more than 7,000 years ago. But raising hogs has become more and more complex. Today, to produce large litters and high-quality pork as quickly as possible, pigs are crossbred.

Pork Production

The use of genetics in a pig nursery is complex and important because breeds of pigs are very specific. Here are the most notable differences among various breeds.

MEAT BREEDS
have high weight gain, a good build, and a high food-conversion efficiency.

Hampshire

Duroc

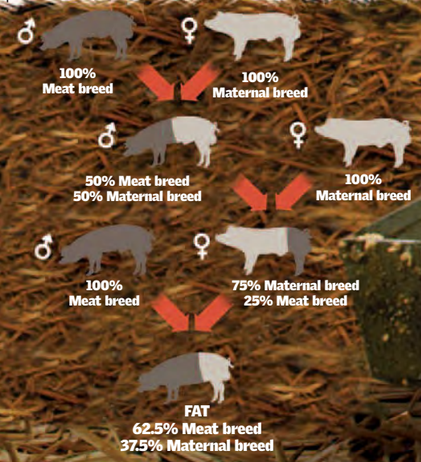
Pietrain

MATERNAL BREEDS
They are very prolific, have good maternal skills, and produce a large number of piglets.

Landrace

Yorkshire

CROSS TO OBTAIN A HOG FOR CONSUMPTION



1 Mountings

Older sows coming from the breeding room and young replacement gilts enter pens where they will be naturally or artificially impregnated.

2 Gestation

Once impregnated, they are taken to the gestation room, where they will remain for 114 days, or until two or three days before giving birth. To prevent problems when they give birth, they receive a restricted diet so they do not get fat.

3 Maternity

They give birth to litters of 10 to 12 animals and can produce over 3 gallons (12 l) of milk daily. Feeding is unrestricted so that the sow is not left weakened after weaning.

4 Raising

The recently weaned piglets enter nursery crates kept at an ambient temperature averaging 77° F (25° C). They are given an initial ration and remain here from day 21 to day 45.

5 Fattening

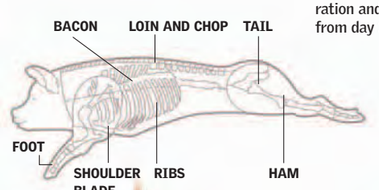
This period lasts approximately 90 days. When the pigs are 150 days old, they weigh about 210 pounds (95 kg).

6 Slaughter

Once they weigh between 210 and 220 pounds (95-100 kg), the pigs are transferred to the slaughterhouse. There they are given an electric shock that renders them unconscious before they are killed. They are scalded in hot water to detach their hair, are bled, and are then eviscerated, and the carcass is prepared for final butchering.

The Cuts

The animal can be sold as a dressed carcass or in pieces and taken to supermarkets. Its meat will be used to make sausages or left as entire cuts.



210 to 220 pounds (95-100 kg)
IS THE WEIGHT OF A PIG WHEN IT IS READY TO BE SLAUGHTERED.

FEED
It is common to use growth hormones to increase food conversion efficiency and the lean-meat content in the dressed carcass.

Milk Production

Until the 18th century, milk was a little-consumed product because it could be kept for only a few hours without spoiling. It was not easy to offer a supply of fresh milk to meet urban needs. Only in the 20th century, after the discovery of pasteurization, allowing milk to be preserved, did milk become a universally popular drink produced industrially.

1. MILKING AND MILK PRESERVATION AT THE FARM
Mechanically milked milk comes out at about 99º F (37° C). It is immediately cooled to less than 39º F (4° C) to prevent spoilage.

KEY
Milk Status
- Raw
- Sterilized
- Skimmed
- Cream
- Homogenized
- Pasteurized

COOLING ROOM

2. COLLECTION
The milk is pH controlled to prevent contamination, and it is removed from the farm in large tanker trucks.

REFRIGERATED TANKER

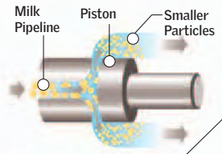
3. ANALYSIS
Once in the plant, the phosphatase test is done: if it is positive, the milk is raw and has not been heated.

4. RECEPTION AND STERILIZATION
Milk is heated to between 135º and 154º F (57-68º C) for transportation or processing, eliminating germs while retaining the properties of raw milk.

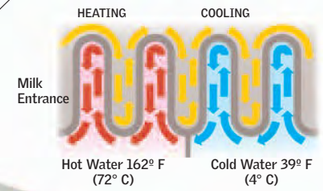
5. SEPARATION
Milk and cream are separated centrifugally. Next, milk products are obtained. For butter and whipped cream, the cream is heated to 260º F (127º C) to reduce its water content. For yogurt and cheese, proportions of milk and cream are mixed together and appropriate bacteria cultures are added.

6. HOMOGENIZATION
ensures that the product is uniform in consistency. It consists of the dispersion of the milk's fat globules by means of friction created under very high pressure.

High-pressure streams of milk collide with a piston, reducing the size of the fat particles.



7. PASTEURIZATION
ensures that potentially harmful microorganisms are eliminated from the milk but does not change the milk's properties. It begins with rapid heating from a source of indirect heat, followed by circulation through a cold pipe for quick cooling.



Louis Pasteur
1822-95
French chemist. Among other things, he discovered that the decomposition of food is caused by bacteria, and he invented the first ways to keep substances from spoiling.

8. BOTTLING
Peroxide solutions are used to sterilize the containers, and reagent strips are used to ensure that no peroxide residue remains.

HOMOGENIZER

WATER HEATER

HEAT EXCHANGE

SEPARATOR

Pasteurized, Homogenized Milk Tank

Skim Milk Tank

Cream Tanks

Internal layers of the separator where cream particles are decanted as grainy sediment

CONTROL ROOM
The various steps of the processes carried out in modern plants are automated and controlled by computers from a central office.

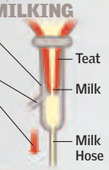
PACKER

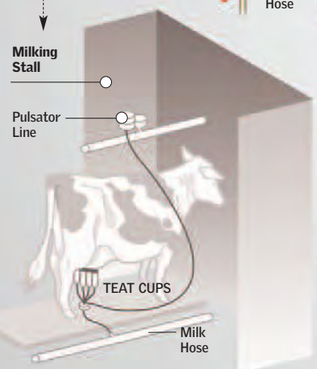
SEALING MACHINE
is maintained in aseptic conditions. Processing and expiration dates are stamped on the container.

FILLING MACHINE
Except in the case of long-life milk, the machine fills containers that will allow the milk to be preserved for two weeks under adequately cold conditions.

ANNUAL PRODUCTION OF FRESH MILK
140 billion gallons

MECHANICAL MILKING





MAIN DAIRY BREEDS

HOLSTEIN-FRIESIAN
From Germany. For more than 300 years, these black and white cows have adapted to different climates.

JERSEY
The most widespread English breed. Its angular frame makes it ideal for milk production.

AYRSHIRE
From southwestern Scotland. The oldest of the milk breeds (17th century). They are notable for their red spots.

MILK PRODUCTS

The Human Threat

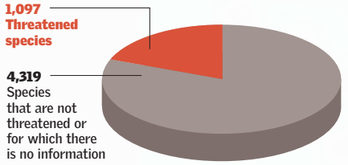
Over the next 30 years, almost a quarter of the mammals could disappear from the face of the Earth, according to the United Nations. The eminent collapse reflects an unequivocally human stamp: hunting, deforestation, pollution, urbanization, and massive tourism. Experts calculate that more than 1,000 mammals are endangered or vulnerable, and 20 areas of the planet have been identified where probabilities of extinction may exist in the near future.

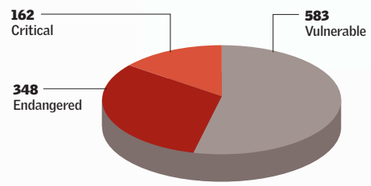
Affected Regions

There are 781 threatened species in the region of sub-Saharan Africa, and in South Asia there are 726. South America contains another 346 endangered species, and Central and North America have 63 endangered mammals.

MAMMALS OF THE WORLD

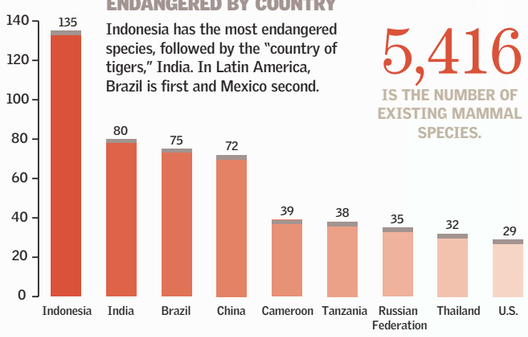
More than one out of every five species of mammals is endangered: 20 to 25 percent of existing mammalian species.





ENDANGERED BY COUNTRY

Indonesia has the most endangered species, followed by the "country of tigers," India. In Latin America, Brazil is first and Mexico second.



Sea Otter

Enhydra lutris

Once a continuous line of sea otter colonies stretched from the Kuril Islands of Japan to California. Today only a few colonies remain in Alaska and in the lower United States.

Dama Gazelle
The degradation of their habitat, as well as unregulated hunting, threaten their existence. In the Sahara, their population fell by 80 percent in only 10 years.

Chinchilla
Chinchilla brevicaudata
They live in the Andes Mountains of Chile and Peru. Indiscriminate hunting has decreased the species, and it is endangered.

Hippopotamus
These are among the most vulnerable animals. From 1994 until today, their population in Zambia and the Democratic Republic of Congo has fallen by 95 percent.

Southern Right Whale

Eubalaena australis

inhabits a broad band extending from 20º S to 60º S. They are sought for their high quantities of body oils, and they are relatively easy to capture. It is estimated that only 3,000 exist today.

Hainan Black-crested Gibbon
Nomascus nasutus sp. *hainanus*
These primates are among the five species in most danger of extinction. Only 30 black-crested gibbons are known to exist.

Orangutans

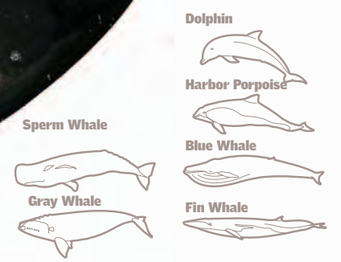
Pongo pygmaeuspygmaeus (Borneo)
Pongo pygmaeus abelii (Sumatra)

Found in the tropical forests of the islands of Borneo and Sumatra. Indiscriminate logging, mining, and forest fires isolate them from nature, as does the illegal capture of their young, which are then sold as pets.

5,416
IS THE NUMBER OF EXISTING MAMMAL SPECIES.

Cetaceans

Gray whales, which inhabit the waters of the northern Pacific and the Arctic, are protected. In 1970, sperm whales were declared endangered, and today hunting them is prohibited. The Indian Ocean has been declared a whale sanctuary in an effort to curb hunting, but 7 out of 13 great whales remain in danger of extinction, as do a similar number of dolphin species.



Giant Panda

Ailuropoda melanoleuca

One thousand bears survive in reserves created in China. The disappearance of their habitat—caused by the felling of bamboo, their natural food—as well as the extreme difficulty they have reproducing in captivity (because of their timidity) are the principal reasons for the decrease in this species.

DEGREE OF THREAT

Extinct	Has not been seen for 30 years
In the Wild	Survives in captivity
Critically Endangered	500 individuals
Endangered	1,000 to 2,000 individuals
Vulnerable	Up to 5,000 individuals

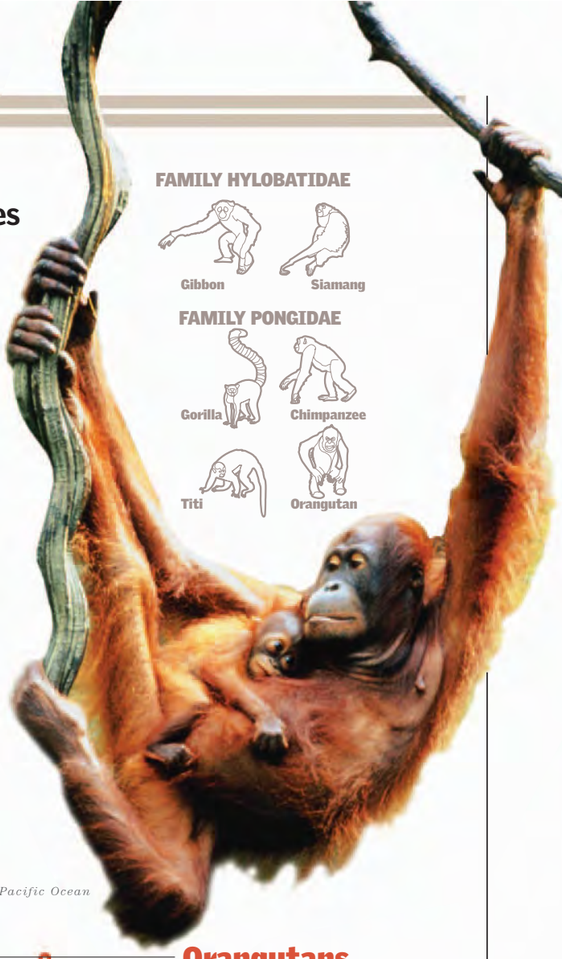
KEY
- MAMMALS AT CRITICAL RISK
- UP TO 10 SPECIES ALREADY EXTINCT
- MORE THAN 10 SPECIES ALREADY EXTINCT

Families of Primates

Twenty-five percent of the 625 species and subspecies of primates are in danger of extinction. The principal causes are deforestation, indiscriminate commercial hunting, and illegal trafficking of animals. In the countries of Gabon and Congo, where the majority of chimpanzees and gorillas live, the population decreased by more than half between 1983 and 2000.

IUCN
The World Conservation Union

The World Conservation Union was created in 1948, bringing together 81 nations and nearly 10,000 specialists.



Glossary

Abomasum

Last of the four chambers into which ruminants' stomachs are divided. It secretes strong acids and many digestive enzymes.

Agouti

Rodent mammal of South America measuring approximately 20 inches (50 cm) and having large feet, a short tail, and small ears.

Albumin

Protein found in abundance in blood plasma. It is the principal protein in the blood and is synthesized in the liver. It is also found in egg whites and in milk.

Alveolar Gland

Functional production unit in which a single layer of milk-secreting cells is spherically grouped, having a central depression called a lumen.

Biome

Land or water ecosystem with a certain type of predominant vegetation and fauna.

Biped

Adjective applied to species of mammals that walk on two feet.

Bradychardia

Lowering of cardiac frequency to below 60 beats per minute in humans.

Bunny

This is a young or growing rabbit.

Carnassial

A typical sharp premolar present in carnivorous animals that helps them cut and tear the flesh of their prey more efficiently.

Carpus

Bone structure of the wrist, located between the bones of the forearm and the metacarpus. It is made up of two rows of bones.

Chiridium

A muscular limb in tetrapods. It is a long bone whose anterior end articulates with the scapular belt. The posterior end articulates with two bones that connect to the joints of the digits.

Cloaca

The open chamber into which the ducts of the urinary and reproductive systems empty.

Cochlea

A structure shaped like a coiled spiral tube, located in the inner ear of mammals.

Concha

The arched, osseous plate found in each of the nostrils.

Cones

The photoreceptor cells in the retina of vertebrates. They are essential for distinguishing colors.

Convolution

Each of the slight elevations or folds that mark the surface of the cerebral cortex.

Cortex

The outer tissue of some organs, such as the brain and kidney.

Counter Shading

The characteristic of protective coloration in the hair or fur of certain mammals that are dorsally dark and ventrally lighter.

Cynodonts

Animals that, beginning in the Triassic Period, start to exhibit characteristics essential to the lives of warm-blooded animals, making them relatives of true mammals. They include the Mammaliaformes.

Dendrite

The branched elongation of a nerve cell by means of which it receives external stimuli.

Dermis

The inner layer of the skin, located under the epidermis.

Dichromatic

Refers to mammals, such as mice and dogs, that have two types of cones in their retinas and can only distinguish certain colors.

Digitigrade

Refers to animals that use only their digits to walk. One example is dogs.

Dimorphism

Two anatomical forms in the same species. Sexual dimorphism is common between males and females of the same species.

Domestication

The process by which an animal population adapts to human beings and captivity through a series of genetic changes that occur over time, as well as by means of adaptation processes brought about and repeated over generations.

Echolocation

The ability to orient and maneuver by emitting sounds and interpreting their echoes.

Ecosystem

A dynamic system formed by a group of interrelated living beings and their environment.

Embryo

A living being in the first stages of its development, from fertilization until it acquires the characteristic appearance of its species.

Endemism

The characteristic of a specific area where animal or plant species are natively and exclusively found.

Endothermy

The ability to regulate metabolism to maintain a constant body temperature independent of the ambient temperature.

Epidermis

The outer layer of the skin formed by epithelial tissue covering the bodies of animals.

Erythrocyte

A spherical blood cell containing hemoglobin, which gives blood its characteristic red color and transports oxygen throughout the body. It is also known as a red blood cell.

Estrus

The period of heat, or greatest sexual receptivity, of the female.

Ethology

The science that studies animal behavior.

Eumelanin

One of the types of melanin, a darkish brown color pigment.

Eutheria

One of the infraclasses into which the Theria subclass is divided, applied to animals that complete their development in the placenta.

Fetlock Joint

In quadrupeds, the limb joint between the cannon bone and the pastern.

Follicle

A small organ in the form of a sac located in the skin or mucous membranes.

Gestation

The state of an embryo inside a woman or female mammal from conception until birth.

Glomerulus

A ball-shaped structure such as the renal glomeruli, which are formed by a tiny ball of capillaries and which filter the blood.

Habitat

The set of geophysical conditions in which an individual species or a community of animals or plants lives.

Hibernation

The physiological state that occurs in certain mammals as an adaptation to extreme winter conditions, exhibited as a drop in body temperature and a general decrease in metabolic function.

Hock

The joint located between the metatarsal and tarsal bones of the hind limbs of a quadruped.

Homeostasis

The set of self-regulating phenomena that keeps the composition and properties of an organism's internal environment constant.

Homeothermy

Thermoregulation characteristic of animals that maintain a constant internal temperature, regardless of external conditions. Body temperature is usually higher than that of the immediate environment.

Hoof

Horny, or cornified, covering that completely envelops the distal extremity of horses' feet.

Iris

The membranous disk of the eye between the cornea and the lens that can take on different coloration. In its center is the pupil, which is dilated and contracted by the muscle fibers of the iris.

Keratin

A protein rich in sulfur, it constitutes the chief element of the outermost layers of mammals' epidermises, including hair, horns, nails, and hooves. It is the source of their strength and hardness.

Lactation

The period in mammals' lives when they feed solely on maternal milk.

Litter

All the offspring of a mammal born at one time.

Mammaliaformes

See Cynodonts.

Mammalogy

The science of studying mammals.

Mammary Gland

One of a pair of external secretion organs characteristic of mammals. It provides milk to the young during lactation.

Marsupial

Mammals whose females give birth to unviable infants, which are then incubated in the ventral pouch, where the mammary glands are located. They belong to the Metatheria infraclass.

Marsupium

The pouch, characteristic of female marsupials, that functions as an incubation chamber. It is formed by a fold of the skin and is attached to the outer ventral wall. The mammary glands are found there, and the offspring complete the gestation period there.

Melanin

The black or blackish-brown pigment found in the protoplasm of certain cells. It gives coloration to the skin, hair, choroid membranes, and so on.

Metacarpus

The set of elongated bones that make up the skeleton of the anterior limbs of certain animals and of the human hand. They are articulated to the bones of the carpus, or wrist, and the phalanges.

Metatheria

The infraclass of the Theria subclass, it contains species that reproduce partially inside the mother and then continue their development inside the marsupium.

Molt

The process by which certain animals shed their skin or feathers; or, when plants shed their foliage.

Monotremata

The only order of the Prototheria subclass, it consists of egg-laying mammals with a marsupium in which they incubate their eggs. The mammary glands are tubular and similar to sweat glands. They are distributed in four families, half of which are now extinct.

Multituberculate

A group of mammals that lived predominantly during the Mesozoic Era and that became extinct during the early part of the Cenozoic Era.

Neuron

A differentiated cell of the nervous system capable of transmitting nerve impulses among other neurons. It is composed of a receptor site, dendrites, and a transmission (or release) site—the axon, or neurite.

Nostril

Each of the openings of the nasal cavities that lead to the outside of the body.

Omasum

A ruminant's third stomach chamber. It is a small organ with a high absorptive capacity. It permits the recycling of water and minerals such as sodium and phosphorus, which may return to the rumen through the saliva.

Oviduct

The duct through which the ova leave the ovary to be fertilized.

Oviparous

Refers to animals that lay eggs outside the mother's body, where they complete their development before hatching.

Papilla

Each of the small, conical elevations on skin or mucous membranes, especially those on the tongue, by means of which the sense of taste functions.

Pasteur, Louis

(1822-95) The French chemist who developed pasteurization and other scientific advances.

Pasteurization

The process that ensures the destruction of pathogenic bacteria and the reduction of benign flora in milk without significantly affecting its physicochemical properties.

Patagium

The very fine membrane that joins the fingers and anterior limbs with the body, feet, and tail of bats.

Pheomelanin

One of the types of melanin, a yellowish-red pigment.

Pheromone

A volatile chemical substance produced by the sexual glands and used to attract an individual for reproductive purposes.

Phylogeny

The origin and evolutionary development of species and, generally, genealogies of living beings.

Placenta

The spongy tissue that completely surrounds the embryo and whose function is to allow the exchange of substances through the blood. It also protects the fetus from infections and controls physiological processes during gestation and birth.

Placentalia

The name by which the species in the Eutheria infraclass orders are also known.

Plantigrade

Refers to mammals that use the entire foot in walking. Humans are plantigrade.

Polyandry

Refers to the relationship in which a female copulates with various males during one breeding period.

Polyestrous

Refers to an animal that has multiple annual breeding, or reproductive, periods.

Polygyny

The social system of certain animals, in which the male gathers a harem of females.

Prototheria

A subclass of the mammal class, it has a single order, Monotremata.

Quadruped

Refers to a four-legged animal.

Rabbit Warren

A burrow that rabbits make to protect themselves and their offspring.

Reticulum

The second chamber of a ruminant's stomach. It is a crossroad where the particles that enter and leave the rumen are separated. Only small particles of less than a 12th of an inch (2 mm) or dense ones greater than 1 ounce per inch (1.2 g per mm) can go on to the third chamber.

Retina

The inner membrane of the eyes of mammals and other animals, where light sensations are transformed into nerve impulses.

Rod

Along with cones, rods form the photoreceptor cells of the retina of vertebrates. They are responsible for peripheral and night vision, though they perceive colors poorly.

Rumen

The first chamber of a ruminant's stomach. It is a large fermentation vessel that can hold up to 220-265 pounds (100-120 kg) of matter in the process of being digested. Fiber particles remain there between 20 and 48 hours.

Ruminate

The process of chewing food a second time, returning food to the mouth that was already in the chamber that certain animals (ruminants) have.

Scapula

Triangular bone, also called the shoulder blade. With the clavicle, it forms the scapular belt.

Scavenger

Animals that eat organic forms of life that have died. They help maintain the equilibrium of the ecosystem by feeding upon dead animals, breaking them down.

Spermaceti

A waxy substance contained in the organ that bears the same name, located in the head of the sperm whale. It is believed that it aids deep dives, although some specialists believe that it may assist echolocation.

Spinal Cord

An extension of the central nervous system. Often protected by vertebrae, this soft, fatty material is the major nerve pathway that carries information to and from the brain and muscles.

Synapsids

These are also known as therapsids and are described as mammal-like reptiles. They are a class of amniotes that were characterized by a single opening in the cranium (fenestra) behind each eye in the temple. They lived 320 million years ago, during the late Carboniferous Period. It is believed that modern mammals evolved from them.

Tapetum Lucidum

A layer of cells located behind the retina of some vertebrates that reflects light toward the retina, increasing the intensity of the light it receives. It heightens the perception of light in near-darkness.

Trichromatic

Refers to mammals whose eyes have three classes of cones—sensitive to red, green, or blue.

Trophic Chain

System formed by a group of living beings that successively feed on each other.

Udder

Saclike organ containing the mammary glands of certain female mammals.

Ungulate

A mammal that supports itself and walks on the tips of its digits, which are covered by a hoof.

Uropatagium

The membrane that bats have between their feet. It also encloses the tail.

Viviparous

Refers to animals in which the embryonic development of offspring occurs inside the mother's body and the offspring emerge as viable young at birth.

Vomeronasal Organ

An auxiliary organ of the sense of smell located in the vomer bone between the nose and the mouth. Sensory neurons detect different chemical compounds, usually consisting of large molecules.

Warren

A burrow where certain animals raise their young.

Weaning

The process by which a mammal ceases to receive maternal milk as its subsistence.

Whiskers

Very sensitive hairs of many mammals. They are often located near the mouth, like a mustache.

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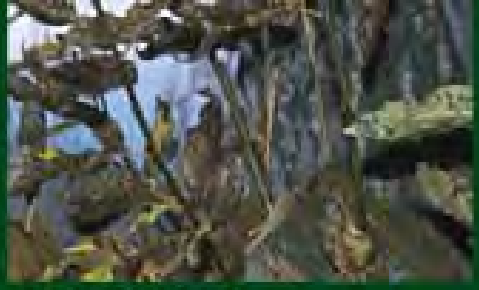

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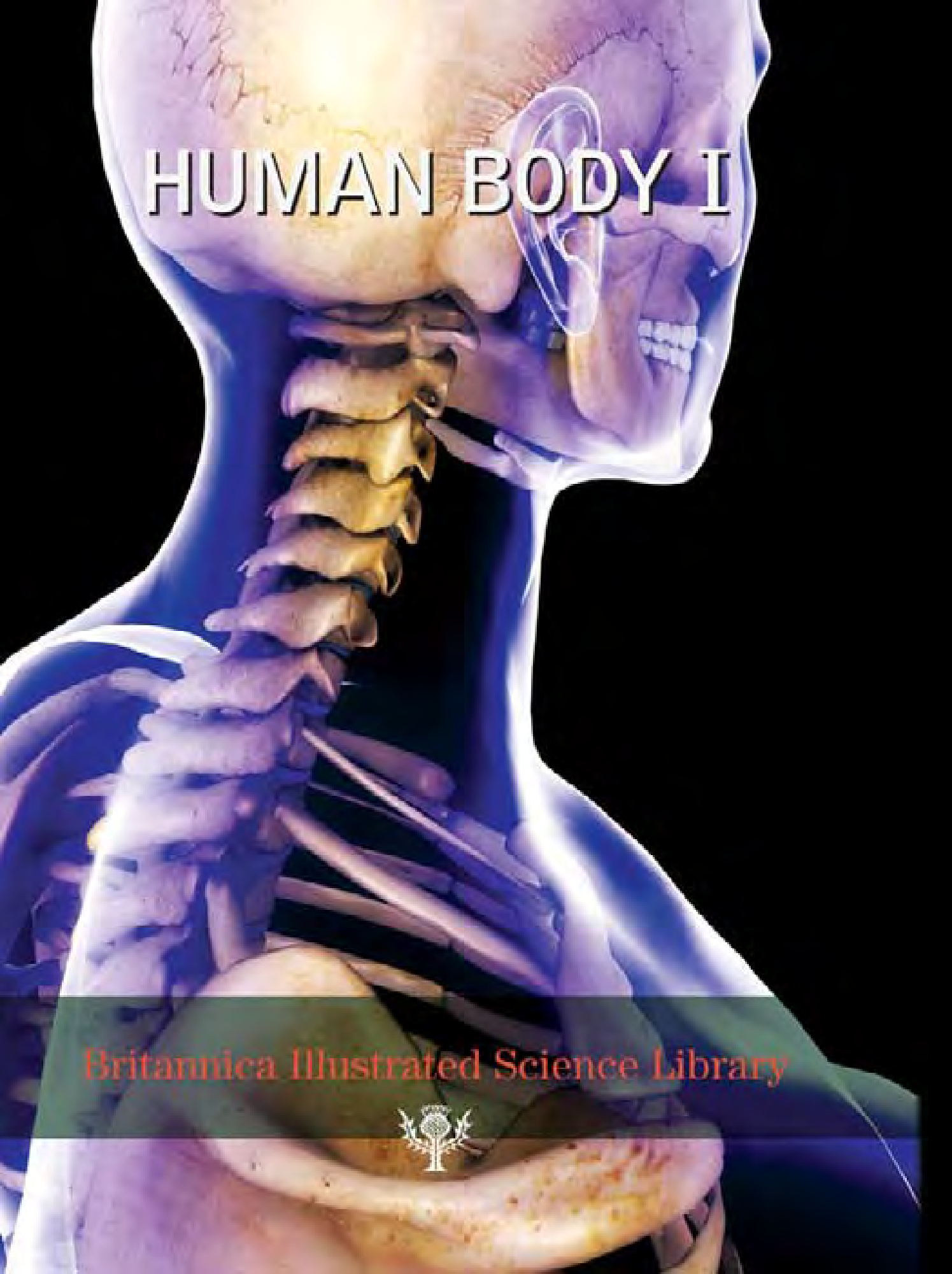
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Human Body I

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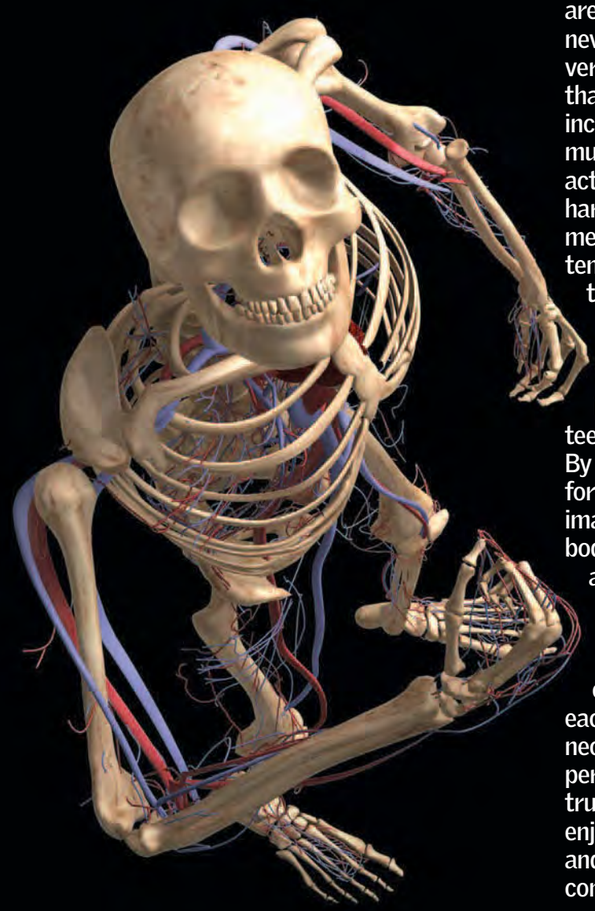

A LIVING STRUCTURE
The skeleton consists of 206 separate bones, which differ in form, size, and name. It supports and shapes the body, protects the internal organs, and—in the bone marrow of certain bones—manufactures various types of blood cells.

A Perfect Machine

How can we understand what we are? What are we made of? Are we aware that all that we do—including reading this book—is the work of a marvelous machine? We know very little about how we are able to be conscious of our own actions; nevertheless, even though we are usually not very aware of it, this community of organs that is the body—an integrated system that includes the brain, heart, lungs, liver, kidneys, muscles, bones, skin, and endocrine glands—acts together in exquisitely regulated harmony. It is interesting that various mechanisms work together to keep the temperature of the body at 98.6° F (37° C); thanks to the dynamic structure of bones and cartilage, the body is maintained in perfect balance. The body also has a fantastic ability to transform the food it ingests into living tissues, bones, and teeth, all of which contribute to its growth. By this same process, we obtain the energy for working and playing. It is hard to imagine that not long ago the cells of the body of the person reading this book were autonomous and were duplicating themselves freely within the walls of a mother's uterus. Certainly no one reading this book could recognize herself or himself in those cells. Nevertheless, each cell carried within it the information necessary for the development of that person. Everything that happens inside us is truly fascinating. Therefore, we invite you to enjoy this book. It is full of incredible facts and illustrations that will show you the complex ways each part of the body works.

What are cells like, and how do they form tissue? What is blood, and why are proteins so important? The heart, usually thought of as the wellspring of love and the emotions, is actually the engine of the circulatory system. It is because of the heart that all the cells of the body receive a constant supply of nutrients, oxygen, and other essential substances. The heart is so powerful that it pumps about 10 pints (4.7 l) of blood per minute. The nervous system is the most intricate of all the body's systems. It works

every second of every day, gathering information about the organism and its surroundings and issuing instructions so that the organism can react. It is this computer that permits us to think and remember and that makes us who we are.

The nervous system is a complex network of sensory cells, originating in the brain and spinal cord, that transmits signals throughout the body, employing a caravan of chemical messengers to make sense of this marvelous complex that we catalogue as touch, taste, smell, hearing, and vision. In fact, at this precise moment, because of an extraordinary relationship between our eyes and our brain, we are able to see and understand what we are reading. Modern cameras are designed on the same basic principles as our eye, but they have never been able to equal the visual power of the eye. The focus and the automatic aperture of the human eye are perfect. Our ears share a similar complexity and allow us to have excellent hearing. The external ear operates by receiving sound waves in the air. Sound waves travel through the auditory canal and are transmitted by the bones of the intermediate ear toward the cochlea, which contains liquid and is spiraled like the shell of a small sea snail. The cochlea converts waves of air into vibrations of liquid, which are detected by special filaments in the ear that are of many lengths and that detect sound waves of different lengths. These filaments then transmit nerve impulses to the brain and provide us with our ability to interpret what we hear. This book will also tell you about the function of our skin, the largest organ of the body, which serves as an elastic barrier covering and protecting everything inside our bodies. Captivating images will show you how each of our extraordinary body systems function, and incredible facts will help you understand why the human body is so amazing.

What Are We Made Of?

MITOSIS
An enlarged view that shows the process of mitosis, the most common form of cellular division

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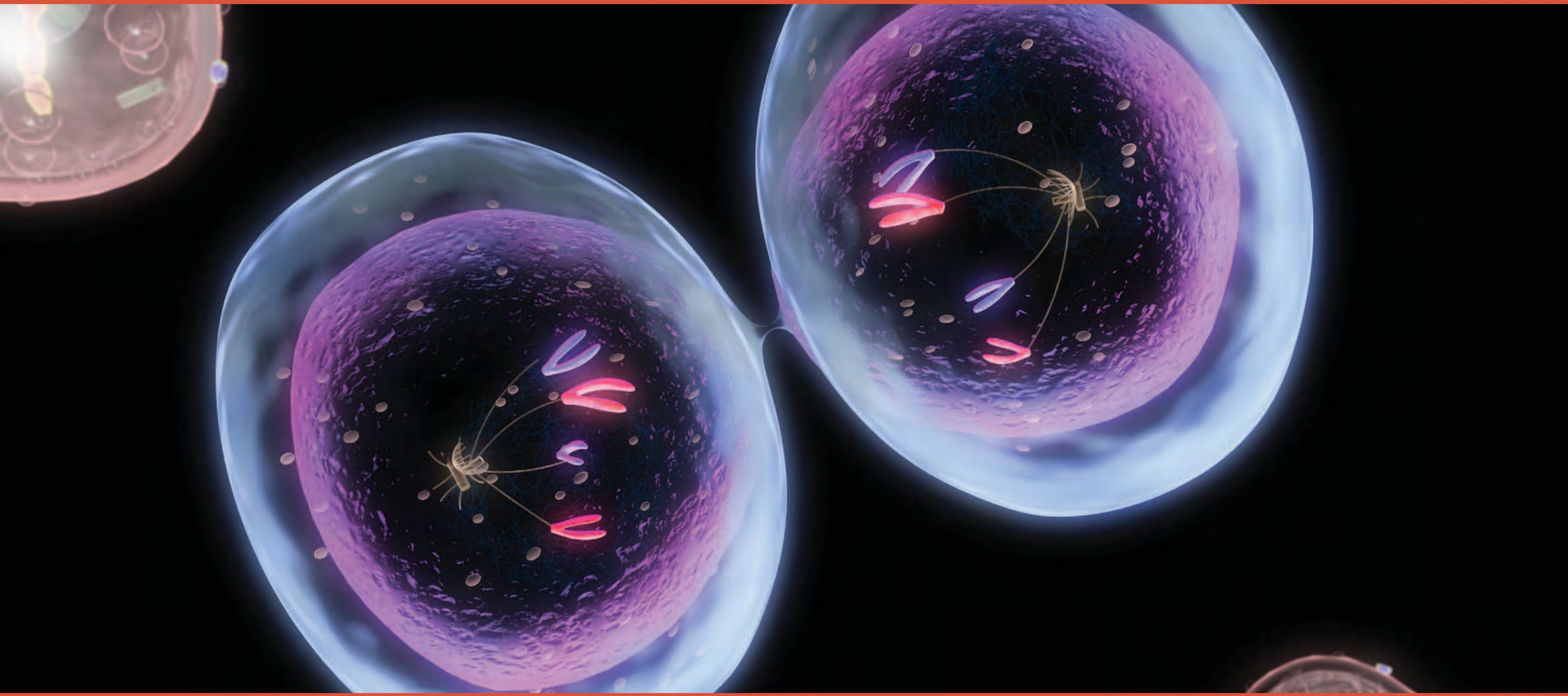
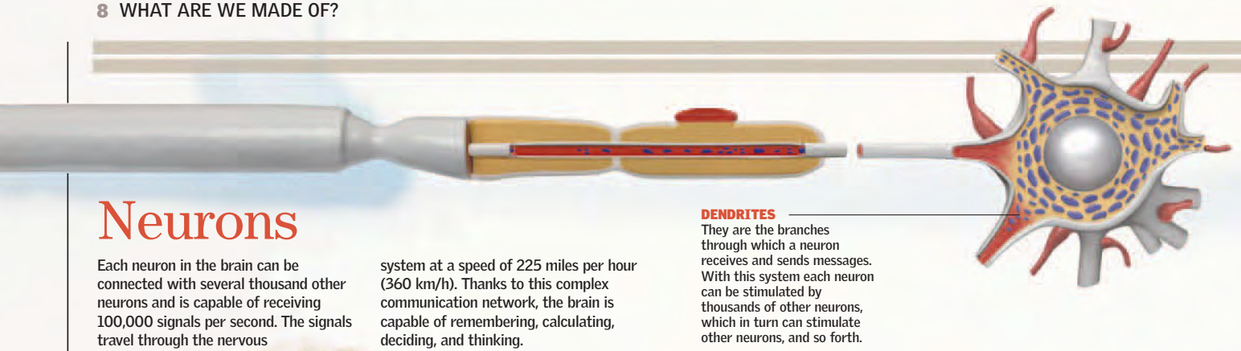


To understand the truest and most elementary characteristics of life, we must begin with the cell-the tiny organizing structure of life in all its forms. Most cells are too small to be observed with the naked eye, but they can be distinguished easily through an ordinary microscope. Human body tissues are groups of cells whose size and shape depend on the specific tissue to which they belong. Did you know that an embryo is a mass of rapidly dividing cells that continue to develop during infancy? We invite you to turn the page and discover many surprising things in this fascinating and complex world. ●



Neurons

Each neuron in the brain can be connected with several thousand other neurons and is capable of receiving 100,000 signals per second. The signals travel through the nervous system at a speed of 225 miles per hour (360 km/h). Thanks to this complex communication network, the brain is capable of remembering, calculating, deciding, and thinking.

DENDRITES
They are the branches through which a neuron receives and sends messages. With this system each neuron can be stimulated by thousands of other neurons, which in turn can stimulate other neurons, and so forth.

Undivided Attention

From birth the infant's brain cells develop rapidly, making connections that can shape all of life's experiences. The first three years are crucial. When neurons receive visual, auditory, or gustatory stimuli, they send messages that generate new physical connections with neighboring cells. The signals are sent through a gap called a synapse by means of a complex electrochemical process. What determines the formation of a person's synapses and neural networks? One key factor is believed to be the undivided attention and mental effort exerted by the person.

Learning

Each child has his or her own intellectual filter; the quality of the filter depends on undivided attention and on how the child responds to a broad variety of stimuli.

225 miles per hour (360 km/h)
THE VELOCITY OF THE NERVOUS SYSTEM'S SIGNALS

Brain

At birth the infant brain contains 100 billion neurons. That is about as many nerve cells as there are stars in the entire Milky Way Galaxy! Then as the infant receives messages from the senses, the cerebral cortex begins its dynamic development.

3 pounds (1.4 kg)
IS THE WEIGHT OF A HUMAN BRAIN.

Respiration

Respiration is usually an involuntary, automatic action that allows us to take in the oxygen we need from the air and exhale carbon dioxide. These gases are exchanged in the pulmonary alveoli.

A WORLD OF SENSATIONS
The tongue recognizes four tastes (sweet, salty, sour, and bitter), and the nasal fossas contain cells that have more than 200 million filaments, called cilia, which are capable of detecting thousands of odors.

THE SENSE OF TOUCH
It is predominant in the fingers and hands. The information is transmitted through neurotransmitters, nerves that carry these impulses to the brain and that serve to detect sensations such as cold, heat, pressure, and pain.

SKIN
The skin is one of the most important organs of the body. It contains approximately five million tiny nerve endings that transmit sensations.

Water and Fluids

Water is of such great importance that it makes up almost two thirds of the human body by weight. Water is present in all the tissues of the body. It plays a fundamental role in digestion and absorption and in the elimination of indigestible metabolic waste. Water also serves as the basis of the circulatory system, which uses blood to distribute nutrients to the entire body. Moreover, water helps maintain body temperature by expelling excess heat through the skin via perspiration and evaporation. Perspiration and evaporation of water account for most of the weight a person loses while exercising. ●

Water Balance and Food

In its continuous process of taking in and eliminating water, one of the most important functions of the body is to maintain a continuous equilibrium between the water that enters and the water that leaves the body. Because the body does not have an organ or other place for storing water, quantities that are lost must be continuously replenished. The human body can survive for several weeks without taking in food, but going without water for the same length of time would have tragic consequences. The human being takes in about 2.5 to 3 quarts (2.5-3 l) of water per day. About half is taken in by drinking, and the rest comes from eating solid food. Some foods, such as fruits and vegetables, consist of 95 percent water. Eggs are 90 percent water, and red meat and fish are 60 to 70 percent water.

60%

THE PERCENTAGE OF A PERSON'S WEIGHT THAT IS DUE TO WATER. IN GENERAL, A 10 PERCENT LOSS OF WATER LEADS TO SERIOUS DISORDERS, AND A LOSS OF 20 PERCENT RESULTS IN DEATH.

HOW THIRST IS CONTROLLED

Thirst is the sensation through which the nervous system informs its major organ, the brain, that the body needs water. The control center is the hypothalamus. If the concentration of plasma in the blood increases, it means the body is losing water. Dry mouth and a lack of saliva are also indications that the body needs water.

HOW WATER IS ABSORBED

Water for the body is obtained primarily by drinking and ingesting food and through internal chemical reactions.

50% of the water comes from ingesting fluids.

35% of the water is obtained from food.

15% comes from metabolic activities.

HOW WATER IS ELIMINATED

Water is expelled not only with urine but also with sweat, through the elimination of feces, and through evaporation from the lungs and skin.

60% is eliminated with urine.

18% is eliminated by sweating and through evaporation from the skin.

14% is eliminated during exhalation by the lungs.

8% is eliminated in excrement.

Chemical Elements

The body contains many chemical elements. The most common are oxygen, hydrogen, carbon, and nitrogen, which are found mainly in proteins. Nine chemical elements are present in moderate amounts, and the rest (such as zinc) are present only in very small amounts, so they are called trace elements.

Mg — **MAGNESIUM 0.05%** Lungs, kidneys, liver, thyroid, brain, muscles, heart

Na — **SODIUM 0.15%** Fluids and tissues, in the form of salt

K — **POTASSIUM 0.3%** Nerves and muscles; inside the cell

S — **SULFUR 0.3%** Contained in numerous proteins, especially in the contractile proteins

Ca — **CALCIUM 1.5%** Bones, lungs, kidneys, liver, thyroid, brain, muscles, heart

Cl — **CHLORINE 0.2%** maintains the equilibrium of water in the blood.

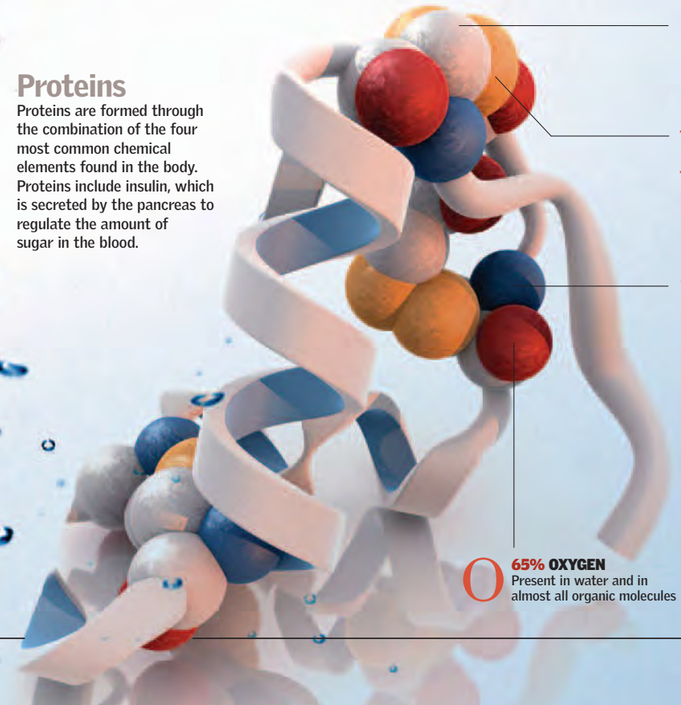
P — **PHOSPHORUS 1%** Urine, bones

Fe — **0.004% IRON** Fluids and tissues, bones, proteins. An iron deficiency causes anemia, whose symptoms include fatigue and paleness. Iron is essential for the formation of hemoglobin in the blood.

I — **0.0004% IODINE** Urine, bones. When consumed, iodine passes into the blood and from there into the thyroid gland. Among its other functions, iodine is used by the thyroid to produce growth hormones for most of the organs and for brain development.

Proteins

Proteins are formed through the combination of the four most common chemical elements found in the body. Proteins include insulin, which is secreted by the pancreas to regulate the amount of sugar in the blood.



C — **18% CARBON** Present in all organic molecules

H — **10% HYDROGEN** Present in water, nutrients, and organic molecules

N — **3% NITROGEN** Present in proteins and nucleic acids

O — **65% OXYGEN** Present in water and in almost all organic molecules

The Cell

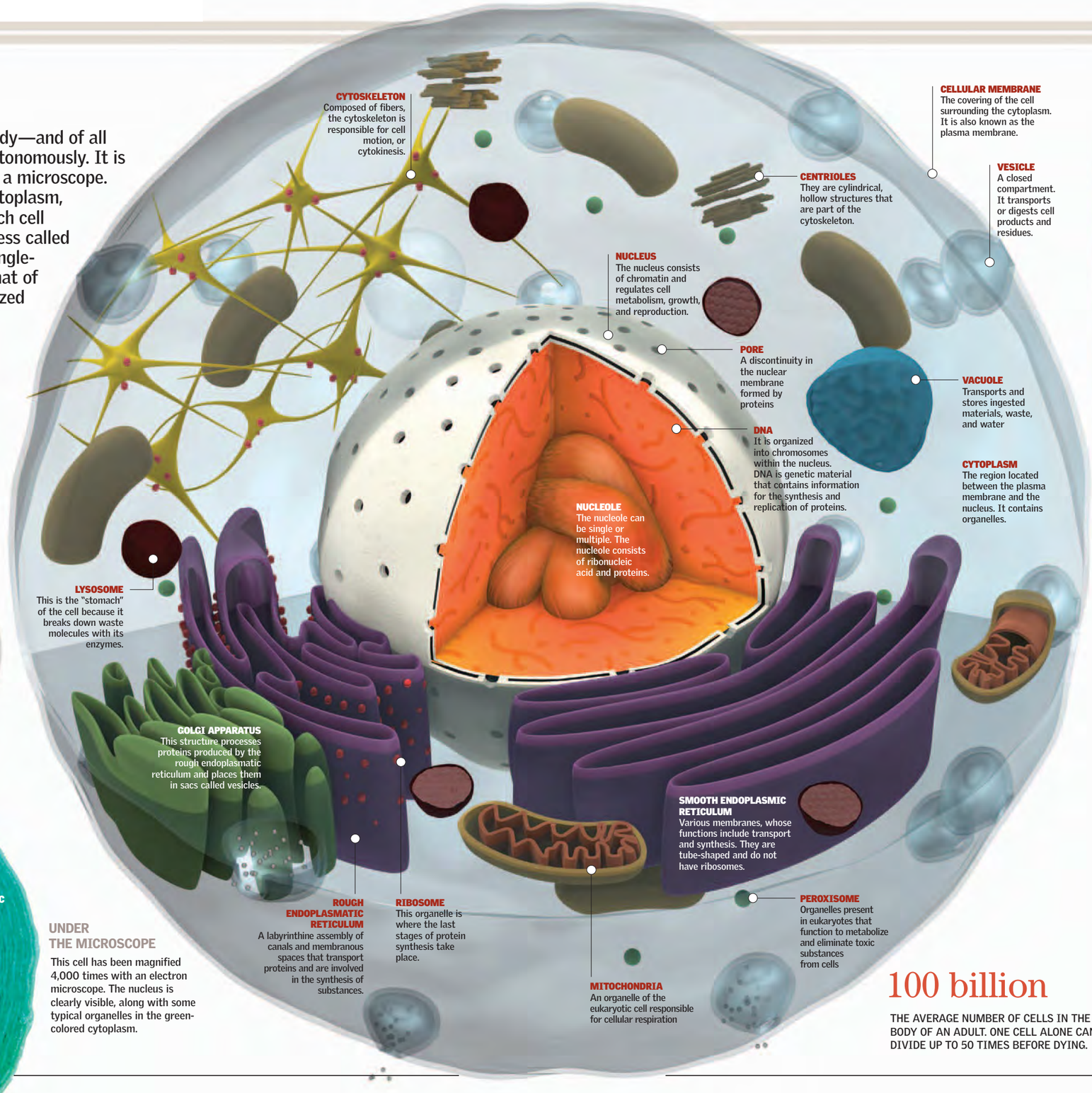
It is the smallest unit of the human body—and of all living organisms—able to function autonomously. It is so small that it can be seen only with a microscope. Its essential parts are the nucleus and cytoplasm, which are surrounded by a membrane. Each cell reproduces independently through a process called mitosis. The animal kingdom does have single-celled organisms, but in a body such as that of a human being millions of cells are organized into tissues and organs. The word "cell" comes from Latin; it is the diminutive of *cella*, which means "hollow." The science of studying cells is called cytology.

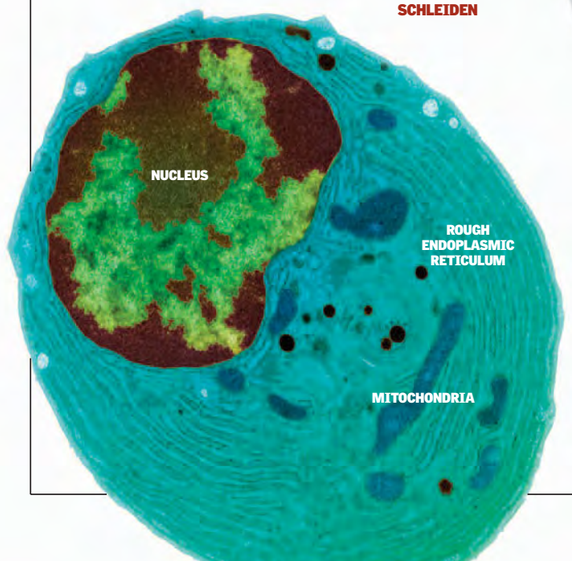
Cell Theory

Before the invention of the microscope, it was impossible to see cells. Some biological theories were therefore based on logical speculations rather than on observation. People believed in "spontaneous generation" because it was inconceivable that cells would regenerate. The development of the microscope, including that of an electronic version in the 20th century, made detailed observation of the internal structure of the cell possible. Robert Hooke was the first to see dead cells in 1665. In 1838 Mathias Schleiden observed living cells, and in 1839, in collaboration with Theodor Schwann, he developed the first theory of cells: that all living organisms consist of cells.

THEODOR SCHWANN

MATHIAS SCHLEIDEN



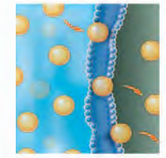


UNDER THE MICROSCOPE

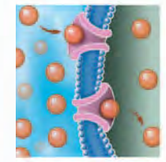
This cell has been magnified 4,000 times with an electron microscope. The nucleus is clearly visible, along with some typical organelles in the green-colored cytoplasm.

TRANSPORT MECHANISMS

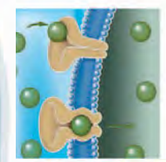
The cell membrane is a semipermeable barrier. The cell exchanges nutrients and waste between its cytoplasm and the extracellular medium via passive and active transport mechanisms.



DIFFUSION It is a passive transport mechanism in which the cell does not use energy. The particles that cross the cell membrane do so because of a concentration gradient. For example, water, oxygen, and carbon dioxide circulate by diffusion.



FACILITATED DIFFUSION Passive transport in which substances, typically ions (electrically charged particles), that because of their size could not otherwise penetrate the cell's bilayer can do so through a pore consisting of proteins. Glucose enters the cell in this way.



ACTIVE TRANSPORT It occurs by means of proteins and requires energy consumption by the cell because the direction of ion transport is against the concentration gradient. In some cells, such as neurons, the Na+/K+ pump uses active transport to move ions into or out of the cell.

Mitochondria

The mitochondria provide large amounts of energy to the cell. They contain a variety of enzymes that, together with oxygen, degrade products derived from glycolysis and carry out cellular respiration. The amount of energy obtained in this process is almost 20 times as great as that released by glycolysis in the cytoplasm. Mitochondria are very different from other organelles because they have a unique structure: an external membrane enclosing an internal membrane with a great number of folds that delimit the internal area, or mitochondrial matrix. In addition, the mitochondria have a circular chromosome similar to that of bacteria that allows the mitochondria to replicate. Cells that need a relatively large amount of energy have many mitochondria because the cells reproduce frequently.

100 billion

THE AVERAGE NUMBER OF CELLS IN THE BODY OF AN ADULT. ONE CELL ALONE CAN DIVIDE UP TO 50 TIMES BEFORE DYING.

Mitosis

It is the cell-division process that results in the formation of cells that are genetically identical to the original (or mother) cell and to each other. The copies arise through replication and division of the chromosomes, or genetic material, in such a way that each of the daughter cells receives a similar inheritance of chromosomes. Mitosis is characteristic of eukaryotic cells. It ensures that the genetic information of the species and the individual is conserved. It also permits the multiplication of cells, which is necessary for the development, growth, and regeneration of the organism. The word "mitosis" comes from the Greek *mitos*, which means "thread," or "weave."

Antioxidants

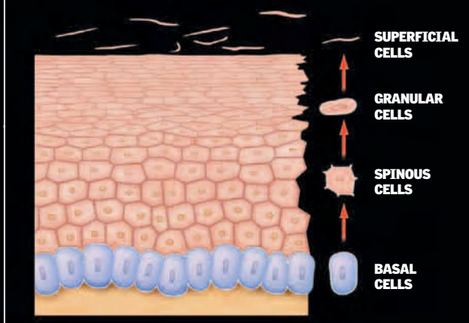
Antioxidants are various types of substances (vitamins, enzymes, minerals, etc.) that combat the pernicious effects of free radicals—molecules that are highly reactive and form as a result of oxidation (when an atom loses an electron), which is often caused by coming into contact with oxygen. A consequence of this oxidative action is the aging of the body. One action of antioxidants is the regulation of mitosis. Preventive geriatrics has focused on using antioxidants to prevent disease and to slow aging, in part because properly regulated mitosis is fundamental to these processes.

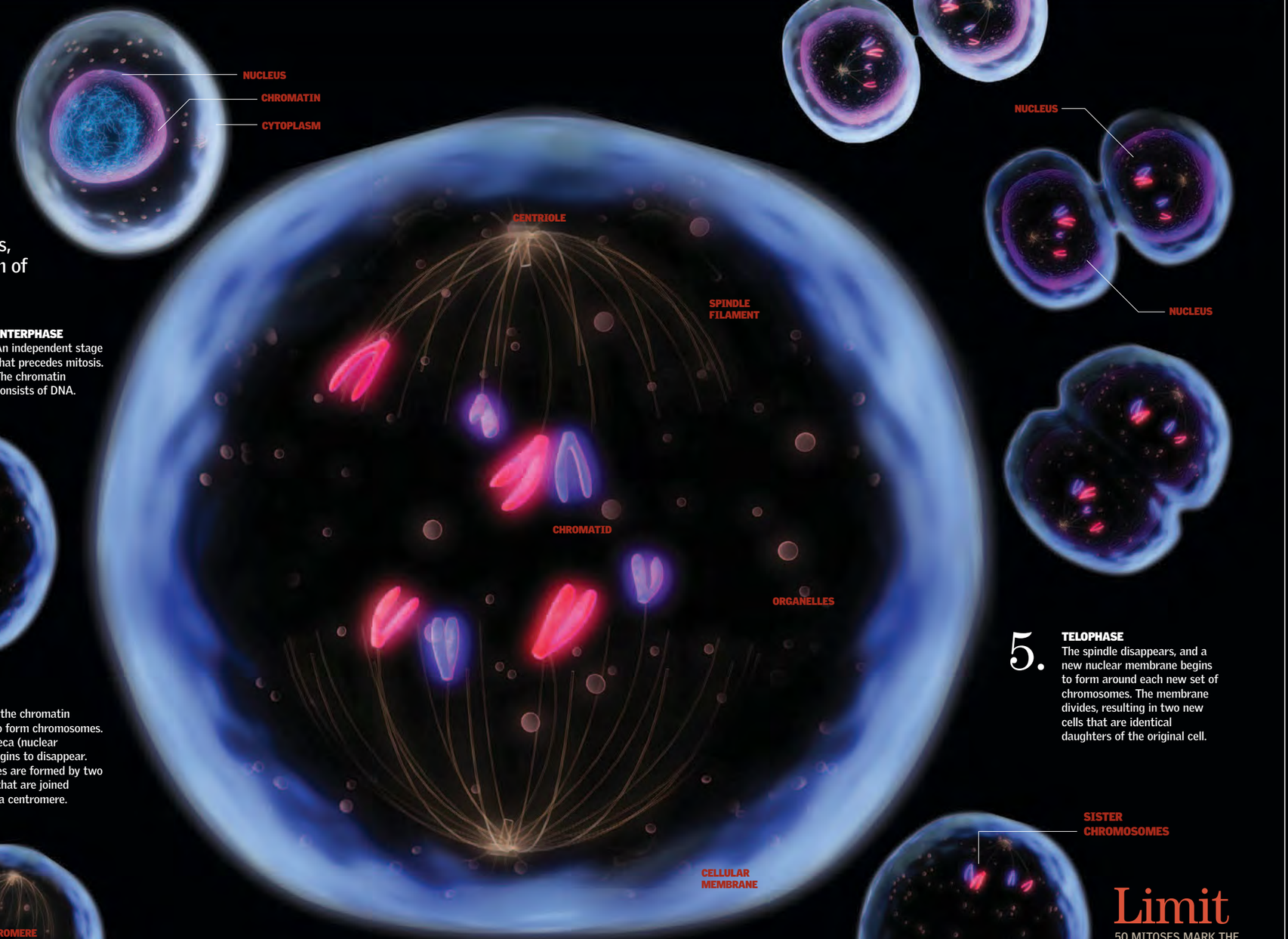
50,000

THE ESTIMATED NUMBER OF CELLS REPLACED EVERY SECOND IN THE HUMAN BODY THROUGH CELLULAR DIVISION

The Ever-Changing Skin

Mitosis, or cellular division, occurs intensely within the skin, a fundamental organ of the sense of touch. The dead cells on the surface are continuously being replaced by new cells, which are produced by mitosis in the lowest, or basal, layer. From there the cells move upward until they reach the epidermis, the outer layer of the skin. A person typically sheds 30,000 dead skin cells every minute.





1. INTERPHASE
An independent stage that precedes mitosis. The chromatin consists of DNA.

2. PROPHASE
In prophase the chromatin condenses to form chromosomes. The karyotheca (nuclear envelope) begins to disappear. Chromosomes are formed by two chromatids that are joined together by a centromere.

3. METAPHASE
It is characterized by the appearance of the spindle. The centromere—the "center" of each chromosome—and the chromatids are joined together and align at the center of the spindle complex. The nuclear membrane disappears.

4. ANAPHASE
In this crucial stage the copies of genetic information separate: the chromatids move apart and form sister chromosomes that migrate to opposite poles of the cell.

5. TELOPHASE
The spindle disappears, and a new nuclear membrane begins to form around each new set of chromosomes. The membrane divides, resulting in two new cells that are identical daughters of the original cell.

Limit

50 MITOSES MARK THE LIFETIME OF A CELL AND ARE KNOWN AS THE "HAYFLICK LIMIT." THIS IDEA IS NAMED AFTER LEONARD HAYFLICK, WHO IN 1961 DISCOVERED THAT THE SECTION OF DNA CALLED THE TELOMERE INFLUENCES CELL LIFE SPAN.

Systems of the Body

The body has various systems with different functions. These functions range from reproducing a cell to developing a new human being, from circulating the blood to capturing oxygen from the air, and from processing food through grinding and chemical transformations to absorbing nutrients and discarding waste. These functions act in harmony, and their interaction is surprisingly efficient.

Circulatory System

This system carries blood to and from the heart and reaches the organs and cells in every part of the body. The supreme pump—the heart—drives the vital fluid—blood—through the arteries and collects it by means of the veins, with a continuous driving impulse that makes the heart the central engine of the body. **See page 36.**

Skeletal System

The skeleton, or skeletal system, is a solid structure consisting of bones that are supported by ligaments and cartilage. The main functions of the system are to give the body form and to support it, to cover and protect the internal organs, and to allow motion to occur. The skeleton also generates red blood cells (called erythrocytes). **See page 20.**

Nervous System

The central nervous system consists of the brain, which is the principal organ of the body, along with the spinal cord. The peripheral nervous system consists of the cranial and spinal nerves. Together they send external and internal sensations to the brain, where the sensations are processed and responded to whether the person is asleep or awake. **See page 82.**

Reproductive System

FEMALE

A woman's internal organs are the vagina, the uterus, the ovaries, and the fallopian tubes. The basic functions of these organs are the production of ova and the facilitation of fertilization of an ovum by a spermatozoon (a mature male sperm cell). When fertilization occurs, it sets a group of processes in motion that result in pregnancy. **See page 66.**

MALE

The various male organs contribute one of the two cells needed to create a new human being. Two testicles (or gonads) and a penis are the principal organs of the system. The system is continuously active, producing millions of tiny cells called spermatozoa. **See page 64.**

Lymphatic System

Its basic functions are twofold. One is to defend the body against foreign organisms, such as bacteria or viruses. The other is to transport interstitial fluid and substances from the digestive system into the bloodstream via the lymphatic drainage system. **See page 42.**

Digestive System

This system is a large tract that changes form and function as it goes from the mouth to the rectum and anus, passing through the pharynx, the esophagus, the stomach, and the small and large intestines. The liver and pancreas help process ingested food to extract its chemical components. Some of these components are welcome nutrients that are absorbed by the system, but others are useless substances that are discarded and eliminated. **See page 50.**

Respiratory System

Air from the external world enters the body through the upper airways. The central organs, the lungs, absorb oxygen and expel carbon dioxide. The lungs send oxygenated blood to all the cells via the circulatory system and in turn receive blood that requires purification. **See page 46.**

Endocrine System

The endocrine system is formed by glands that are distributed throughout the body. Its primary function is to produce approximately 50 hormones, the body's chemical messengers. The endocrine system secretes the hormones into the bloodstream so that they can reach the organs they are designed to influence, excite, or stimulate for such activities as growth and metabolism. **See page 62.**

Muscular System

Its function is to define the shape of the organism and protect it. The muscular system is essential for producing movement. It consists of muscles, organs made of fleshy tissue, and contractile cells. There are two types of muscles: striated and smooth. Striated muscles are attached to the bones and govern voluntary movement. Smooth muscles also obey the brain, but their movement is not under voluntary control. The myocardium, the muscle tissue of the heart, is unique and is in a class by itself. **See page 30.**

Urinary System

This system is a key system for homeostasis—that is, the equilibrium of the body's internal conditions. Its specific function is to regulate the amount of water and other substances in the body, discarding any that are toxic or that form an unnecessary surplus. The kidneys and the bladder are the urinary system's principal organs. The ureters transport the urine from the kidneys to the bladder, and the urethra carries the urine out of the body. **See page 58.**

Bones and Muscles

MUSCLES OF THE THORAX
They play an important role in breathing by facilitating the contraction and expansion of the thoracic cavity.

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MUSCULAR SYSTEM 30-31
MUSCLE FIBER 32-33

The musculoskeletal system consists of the skeletal system of bones, attached to each other by ligaments to form joints, and the skeletal muscles, which use tendons to attach muscles to bone. The skeleton gives resistance and stability to the body and serves as a support structure for the muscles to work and produce movement. The bones also serve as a shield to protect the internal organs. In this chapter you will see in detail—even down to the inside of a muscle fiber—how each part works. Did you know that bones are constantly being regenerated and that, besides supporting the body, they are charged with producing red blood cells? In this chapter you will find incredible images, curiosities, and other information. ●

Skeleton

The skeleton, or the skeletal system, is a strong, resistant structure made up of bones and their supporting ligaments and cartilage. The skeleton gives the body form and structure, covers and protects the internal organs, and makes movement possible. The bones store minerals and produce blood cells in the bone marrow.

Well-Defined Form

The structure of the skeleton can be described as a vertical column of chained vertebrae with a pair of limbs at each end and topped off by the cranium. The upper limbs, or arms, are connected to the shoulder blades and clavicles in what is called the scapular belt, and the lower limbs, or legs, are connected at the hips, or pelvic belt. The joints reach such a level of perfection that modern engineering often uses them as a model in the study of levers when designing such objects as cranes or desk lamps. Although the bones that make up the skeleton are solid, they have a flexible structure and to a large degree consist of spongy tissue. Nevertheless, a small bone is capable of supporting up to 9 tons without breaking. A comparable weight would crush a block of concrete. For a long time anatomists thought that bones themselves were not alive and that their strength merely provided support for the other organs. Modern medicine recognizes that bones are actively living, furnished with nerves and supplied with blood.

Types of Bones

Depending on their characteristics, such as size or shape, the bones of the human body are generally classified as follows:

SHORT BONES: have a spherical or conical shape. The heel bone is a short bone.

LONG BONES: have a central section that lies between two end points, or epiphyses. The femur is a long bone.

FLAT BONES: form thin bony plates. Most bones of the cranium are flat bones.

IRREGULAR BONES: take various shapes. The sphenoids ("wedgelike" bones) in the skull are irregular bones.

SESAMOID BONES: are small and round. The patella and the bones between tendons and in the joints of the hands and feet are sesamoid bones.

Axial Bones

The body has 80 of these bones, which belong to the part of the skeleton formed by the spinal column, the ribs, and the cranium.

208 bones

The total number of bones in the body is between 206 and 208, depending on the individual. The variation occurs with the supernumerary bones (bones of the skull) and the sesamoids (bones found in the joints of the hands and feet or embedded within tendons).

Leonardo

In the Renaissance, the cradle of modernity, Leonardo da Vinci was one of the first to make precise drawings of human bones. Such drawings were needed for studying anatomy since there were no photographs or X-rays.

17 inches (43 cm)

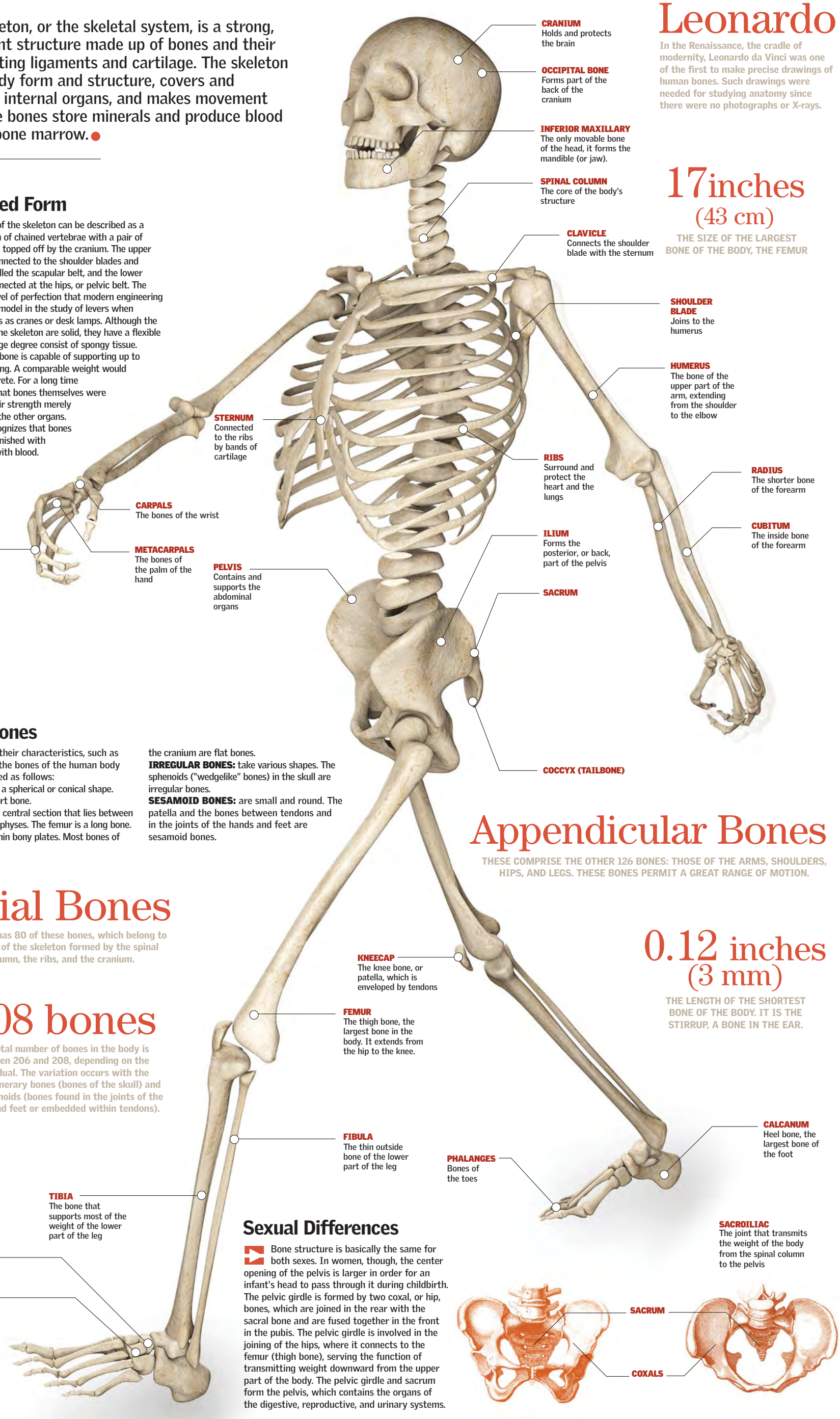
THE SIZE OF THE LARGEST BONE OF THE BODY, THE FEMUR

Appendicular Bones

THESE COMPRISE THE OTHER 126 BONES: THOSE OF THE ARMS, SHOULDERS, HIPS, AND LEGS. THESE BONES PERMIT A GREAT RANGE OF MOTION.

0.12 inches (3 mm)

THE LENGTH OF THE SHORTEST BONE OF THE BODY. IT IS THE STIRRUP, A BONE IN THE EAR.



Sexual Differences

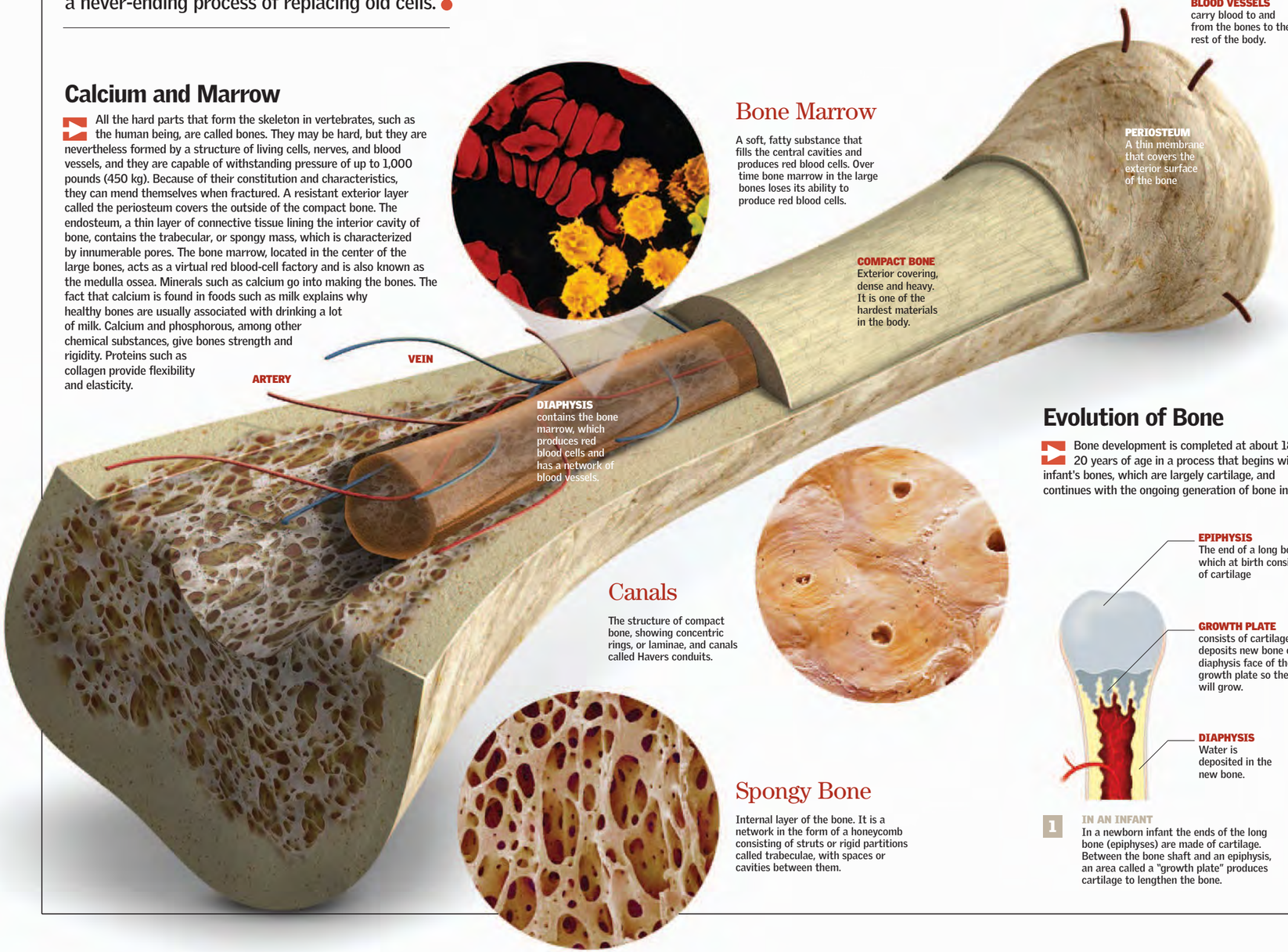
Bone structure is basically the same for both sexes. In women, though, the center opening of the pelvis is larger in order for an infant's head to pass through it during childbirth. The pelvic girdle is formed by two coxal, or hip, bones, which are joined in the rear with the sacral bone and are fused together in the front in the pubis. The pelvic girdle is involved in the joining of the hips, where it connects to the femur (thigh bone), serving the function of transmitting weight downward from the upper part of the body. The pelvic girdle and sacrum form the pelvis, which contains the organs of the digestive, reproductive, and urinary systems.

Bony Tissue

The primary mission of the bones is to protect the organs of the body. Bones are solid and resilient, which allows them to endure blows and prevent damage to the internal organs. The hard exterior is balanced by the internal spongy part. Over a person's lifetime bones are continuously regenerated; this process continues even after a person reaches maturity. Besides supporting the body and enabling movement, the bones are charged with producing red globules: thousands of millions of new cells are produced daily in the bone marrow, in a never-ending process of replacing old cells.

Calcium and Marrow

All the hard parts that form the skeleton in vertebrates, such as the human being, are called bones. They may be hard, but they are nevertheless formed by a structure of living cells, nerves, and blood vessels, and they are capable of withstanding pressure of up to 1,000 pounds (450 kg). Because of their constitution and characteristics, they can mend themselves when fractured. A resistant exterior layer called the periosteum covers the outside of the compact bone. The endosteum, a thin layer of connective tissue lining the interior cavity of bone, contains the trabecular, or spongy mass, which is characterized by innumerable pores. The bone marrow, located in the center of the large bones, acts as a virtual red blood-cell factory and is also known as the medulla ossea. Minerals such as calcium go into making the bones. The fact that calcium is found in foods such as milk explains why healthy bones are usually associated with drinking a lot of milk. Calcium and phosphorous, among other chemical substances, give bones strength and rigidity. Proteins such as collagen provide flexibility and elasticity.



Canals

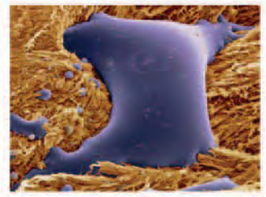
The structure of compact bone, showing concentric rings, or laminae, and canals called Havers conduits.

Spongy Bone

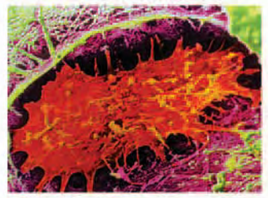
Internal layer of the bone. It is a network in the form of a honeycomb consisting of struts or rigid partitions called trabeculae, with spaces or cavities between them.

TWO TYPES OF BONE CELLS

The osseous tissue consists of two types of cells, osteoblasts and osteoclasts. Both are produced by the bone marrow, and their interaction and equilibrium ensure the integrity and continuous renewal of the bone. An osteoclast reabsorbs bone tissue, leaving empty spaces, and an osteoblast fills them. The function of the osteocytes, a variant of the osteoblasts, is to maintain the shape of the bone.



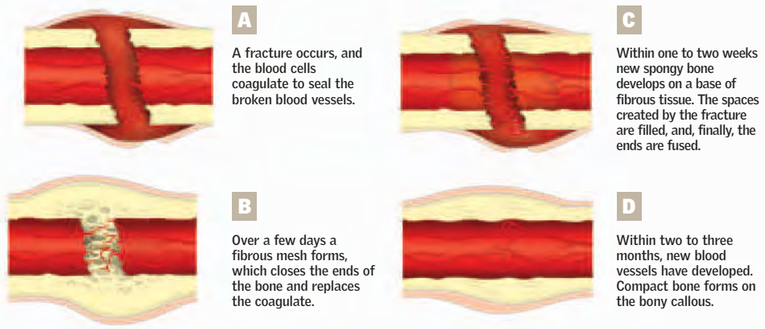
OSTEOBLAST produces osseous, or bone, tissue, which maintains the strength of the bone.



OSTEOCLAST breaks down the tissue so that it can be replaced with newer tissue.

WHY FRACTURES HEAL

Bone has great regenerative capacity. Bone tissue has an extraordinary ability to repair itself after a fracture through processes that include the relatively rapid generation of cells. Medicine can guide these processes to cure other lesions, deformities, etc.



A A fracture occurs, and the blood cells coagulate to seal the broken blood vessels.

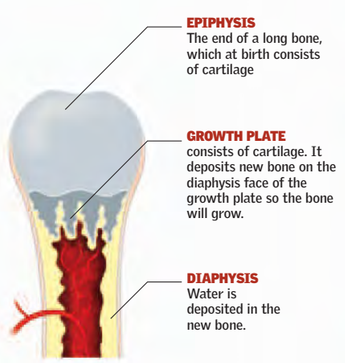
B Over a few days a fibrous mesh forms, which closes the ends of the bone and replaces the coagulate.

C Within one to two weeks new spongy bone develops on a base of fibrous tissue. The spaces created by the fracture are filled, and, finally, the ends are fused.

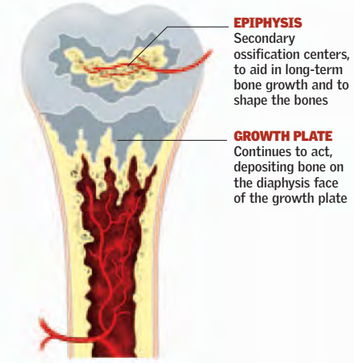
D Within two to three months, new blood vessels have developed. Compact bone forms on the bony callous.

Evolution of Bone

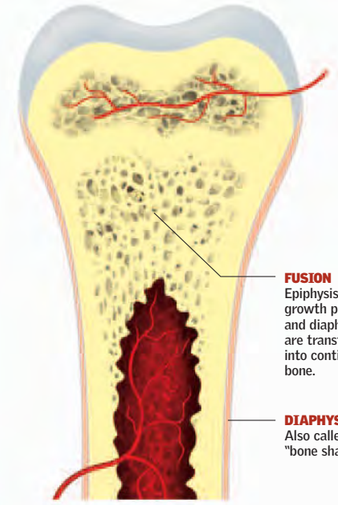
Bone development is completed at about 18 or 20 years of age in a process that begins with an infant's bones, which are largely cartilage, and continues with the ongoing generation of bone in the person as an adult. Calcium is an indispensable element for the healthy development of bones through this process. Until the age of six months, an intake of 0.007 ounce (210 mg) of calcium per day is recommended.



1 IN AN INFANT
In a newborn infant the ends of the long bone (epiphyses) are made of cartilage. Between the bone shaft and an epiphysis, an area called a "growth plate" produces cartilage to lengthen the bone.



2 IN A CHILD
In a child ossification continues to completion during epiphysis, generating long-term bone growth.



3 IN AN ADULT
The process is complete when a person reaches about 18 years of age. The epiphysis, growth plates, and bone shaft fuse and become ossified into a continuous bone.

Cranium and Face

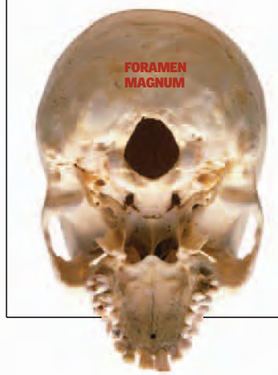
The cranium surrounds and protects the brain, cerebellum, and cerebral trunk (sometimes called the encephalus). In an adult the cranium consists of eight bones that form the skull and the base of the cranium. The face is the anterior part of the skull. It consists of 14 bones, all of which are fixed except the lower maxillary, which makes up the mandible. The total number of bones in the head as a whole exceeds the total of the face and cranium (22) because it includes the little bones of the middle ear.

Sutures and Fontanels

The cranium can be compared to a sphere, which consists of separate bones at birth and closes completely at maturity. The narrow separations between the bones, which appear as lines in the fetus for the first months of its life, are called sutures. Spaces called fontanels form where the sutures meet. Their separation has the functional purpose of allowing the brain to grow. Therefore, when brain growth is complete, the sphere closes tightly, because its function is to protect the brain.

Vibration

When a person speaks, the bones of the cranium vibrate. In Japan a technology was developed based on this vibration. In 2006 the firefighters of the Madrid municipality in Spain adopted this technology. A helmet, furnished with a cranial contact microphone, amplifies the vibrations produced in the bones of the cranium during speech and sends them to radio equipment.



Foramen Magnum

In Latin this term means "big hole." It is a circular opening, also called the occipital orifice, which is located at the base of the cranium. The foramen magnum allows for the passage of the spinal column, the medulla oblongata, the vertebral arteries, and the spinal nerve. The placement of the foramen magnum toward the bottom of the skull is associated with more highly evolved species.

Cranial Bones (8)

PARIETAL (2)
The superior and lateral parts of the cranium

OCCIPITAL (1)
Together with the temporals, it forms the base of the cranium.

FRONTAL (1)
It makes up the forehead.

TEMPORAL (2)
The lateral part of the cranium

SPHENOID (1)
The front part of the base of the cranium and part of the orbital bone (eye socket)

ETHMOID (1)
Upper part of the nasal cavity

Facial Bones (14)

ZYGOMATIC (2)
The cheekbones

PALATINES (2)
Internal bones that form the roof of the mouth

LACHRYMAL BONES (2)
form the eye socket.

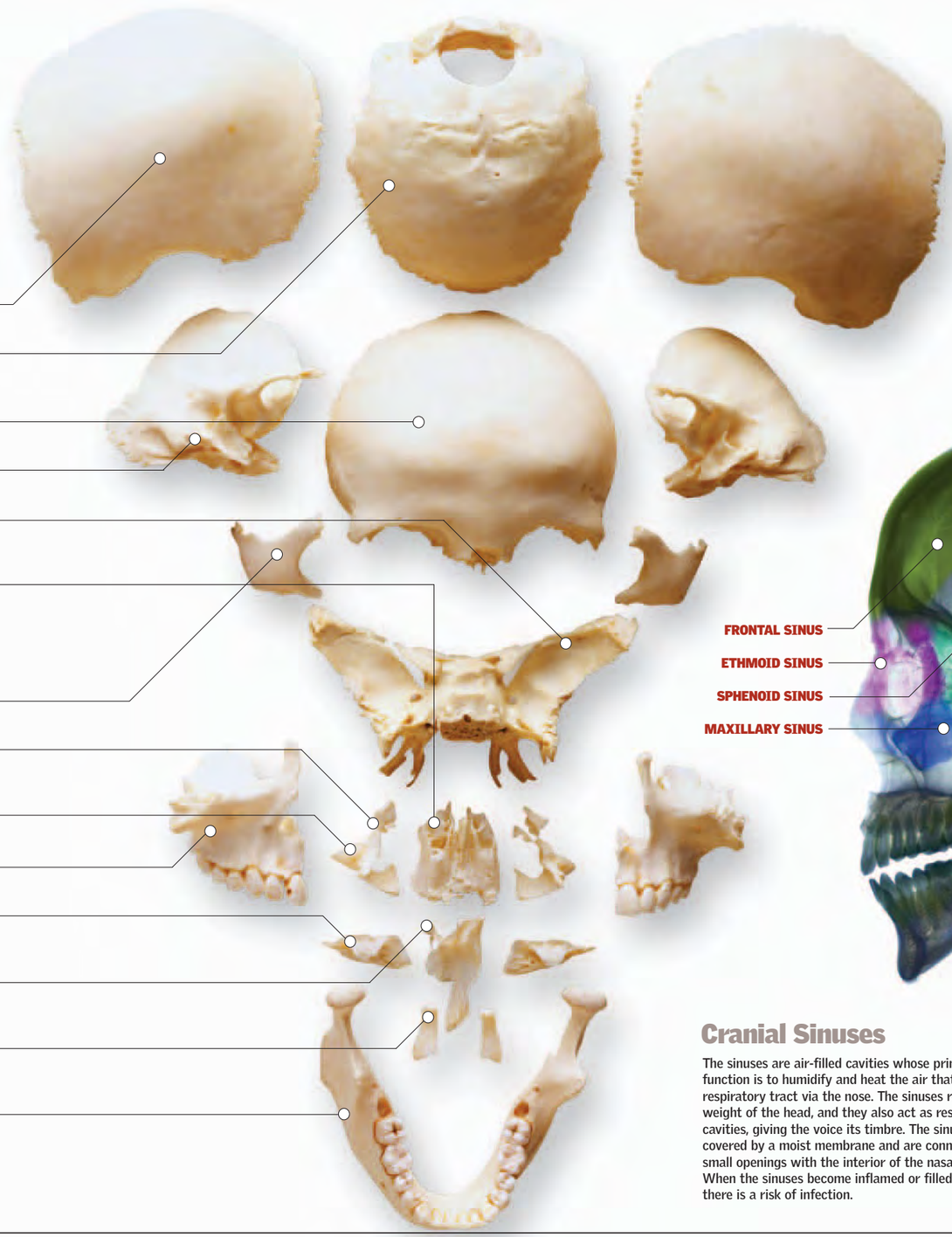
SUPERIOR MAXILLARIES (2)
The upper mandible

NASAL CONCHAS (2)
Independent of the ethmoid conchas

VOMER (1)
divides the nasal cavity into two halves.

NASAL BONE (2)
forms the bridge of the nose (the rest of the nose is cartilage).

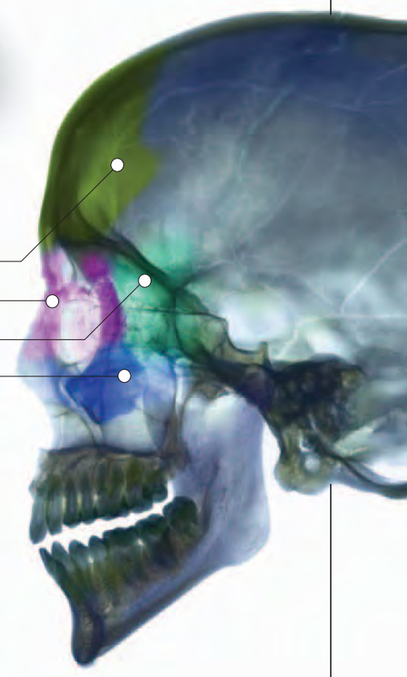
INFERIOR MAXILLARY (1)
constitutes the mandible and is the only facial bone that can move freely.



22
THE TOTAL NUMBER OF BONES IN THE CRANIUM

9 pounds (4 kg)
THE WEIGHT OF AN ADULT HUMAN HEAD

83 cubic inches (1,360 cu cm)
THE TYPICAL VOLUME OF THE CRANIUM



Cranial Sinuses

The sinuses are air-filled cavities whose principal known function is to humidify and heat the air that enters the respiratory tract via the nose. The sinuses reduce the weight of the head, and they also act as resonance cavities, giving the voice its timbre. The sinuses are covered by a moist membrane and are connected via small openings with the interior of the nasal cavity. When the sinuses become inflamed or filled with mucus, there is a risk of infection.

The Great Axis of the Body

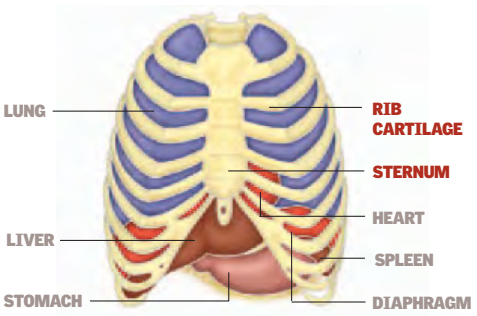
The vertebral, or spinal, column is the flexible axis that lends support to the body. It consists of a series of bones jointed together in a line, or chain, called the vertebrae. The spinal column forms a protective inner channel through which the spinal cord runs. The ribs perform a similar function, wrapping and shielding the vital internal organs, which include the heart and lungs.

Stability and Motion

The vertebrae have a centrum that allows them to support the body's weight, each vertebra upon the next, as well as the weight of the rest of the body. The vertebrae also have extensions that allow them to articulate with other vertebrae or act as supports for the ligaments and the muscles. This system gives the axis of the body both strength and flexibility. In addition, most of the nerves of the peripheral system (that is, those responsible for voluntary movement, for pain, and for the sense of touch) are connected to the spinal cord inside the spinal column. In the centrum the vertebrae are separated from each other by intervertebral disks that are made of cartilage and have a gelatinous interior. When an intervertebral disk is damaged, some of this material can escape and pinch a nerve. This condition, called a herniated disk, can be very painful.

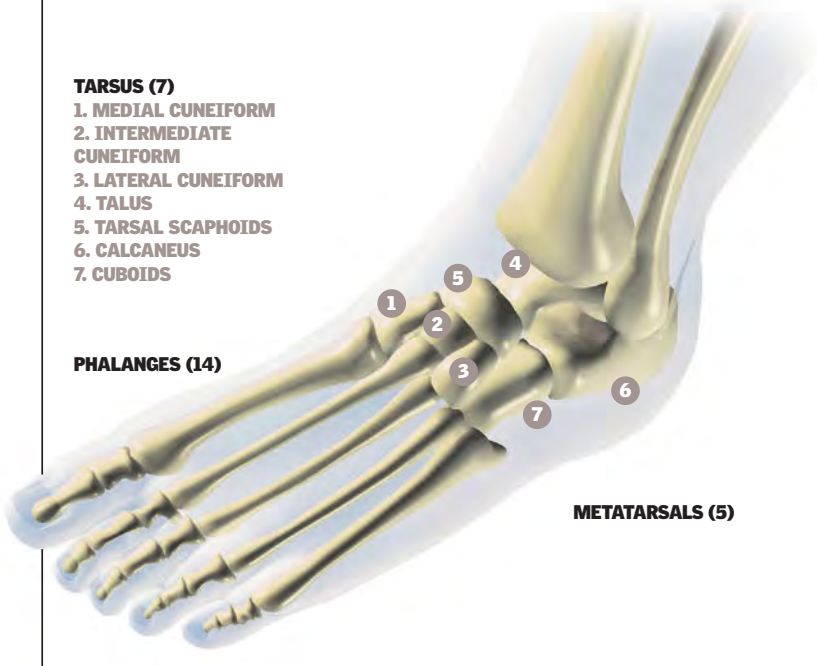
The Ribs and the Rib Cage

The 12 pairs of ribs, which also extend from the spinal column, protect the heart, lungs, major arteries, and liver. These bones are flat and curved. The seven upper pairs are called "true ribs," and they are connected to the sternum (a flat bone consisting of fused segments) by cartilage. The next two or three pairs (called "false ribs") are connected indirectly. The remaining pairs ("floating ribs") are not attached to the sternum. The rib cage, formed by the ribs and its muscles, is flexible: it expands and contracts during breathing.



33 bones

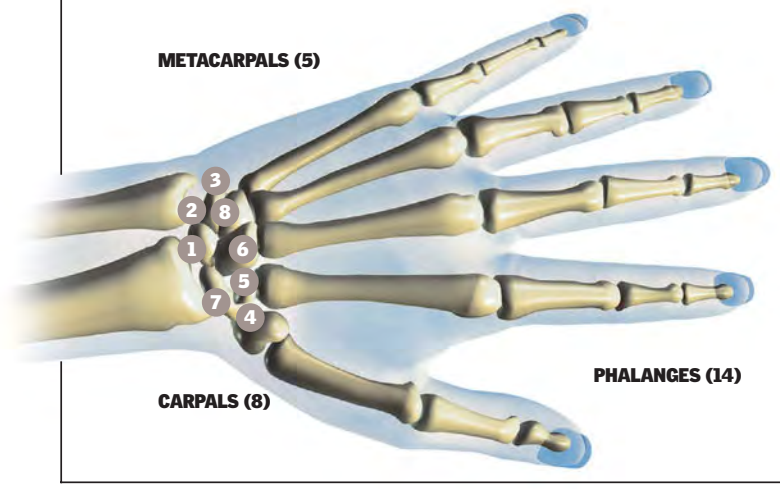
OR VERTEBRAE, MAKE UP THE SPINAL COLUMN. DEPENDING ON THE INDIVIDUAL, SOMETIMES THERE ARE 34. THEY ARE CONNECTED BY DISKS OF CARTILAGE THAT ACT AS SHOCK ABSORBERS. THE SACRUM AND THE COCCYX ARE A RUDIMENTARY TAIL LOST DURING EVOLUTION.

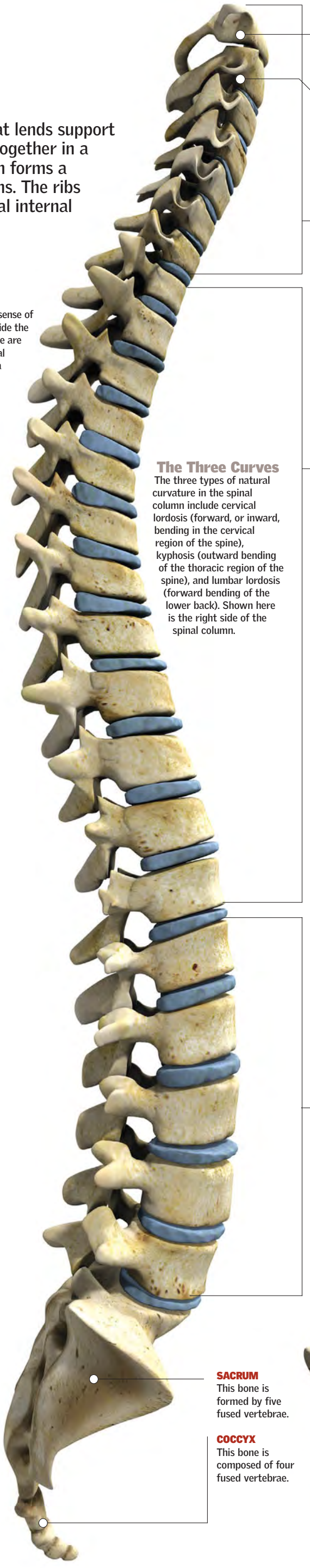


Bones of the Hands and Feet

Each hand (see the drawing below) has 27 bones, and each foot (see above) has 26. The hand has great mobility, and each of its fingers (five in all) has three phalanges (distal, medial, and proximal), except for the thumb, which has two. The complex of carpal bones makes up the wrist and is connected to the forearm. The metacarpal bone sustains the medial part. The feet function in a similar manner; the toes have first, second, and third phalanges, except for the big toe.

CARPALS (8)
1. LUNATE
2. PISIFORM
3. TRIQUETRUM
4. TRAPEZIUM
5. TRAPEZOID
6. CAPITATE
7. SCAPHOID
8. HAMATE





ATLAS
This bone is the first of the seven cervical bones; it unites the spinal column with the head.

AXIS
The second cervical vertebra. Together with the atlas, it permits the movement of the head.

CERVICAL
These seven vertebrae (including the atlas and the axis) support the head and the neck.

THORACIC, OR DORSAL, VERTEBRAE
There are 12, and they are joined to the ribs.

The Three Curves

The three types of natural curvature in the spinal column include cervical lordosis (forward, or inward, bending in the cervical region of the spine), kyphosis (outward bending of the thoracic region of the spine), and lumbar lordosis (forward bending of the lower back). Shown here is the right side of the spinal column.

PARTS OF THE VERTEBRAE

1. SPINAL APOPHYSIS
2. TRANSVERSE APOPHYSIS (2)
3. ARTICULAR APOPHYSIS (4) (2 SUPERIOR AND 2 INFERIOR)
4. LAMINAE (2)
5. PEDICULAE (2)
6. FORAMEN MAGNUM
7. BODY

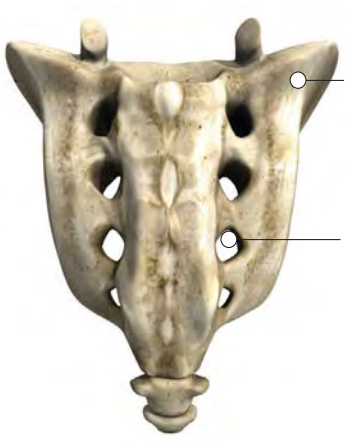
Downwards

All the vertebrae except the cervical axis and atlas have a cylindrical body, which gives them a particular characteristic: as they approach the pelvis they tend to be longer and stronger.

LUMBAR VERTEBRAE
There are five of them, and they bear the weight of the upper part of the body.

SACRUM
This bone is formed by five fused vertebrae.

COCCYX
This bone is composed of four fused vertebrae.



BLADE

SACRAL CANAL
Nerves pass through the sacral canal.

Joints

They are the structures where two or more bones come together, either directly or by means of strong fibrous cords called ligaments. The skeleton has movement thanks to its joints. Most joints, like the knee, are synovial joints. They are characterized by mobility, versatility, and lubrication. The muscles that surround them contract to cause movement. When they work as a whole, the bones, muscles, and joints—together with the tendons, ligaments, and cartilage—constitute a grand system that governs the motor activity of the body and allows us to carry out our daily physical activities. ●

Hypermobility

The versatility of the joints refers to their characteristic range of motion. Just as there are mobile, semimobile, and fixed joints, there is also a group of joints that are hypermobile. Such joints are less common but are easily recognizable, especially in children and adults who have not lost the flexibility of their joints. The elbows, wrists, fingers, and knees can at an early age and in certain individuals have a greater-than-normal range of motion. For people with hypermobile joints this extra range of motion can be accomplished without difficulty or risk of dislocation.

Mobile

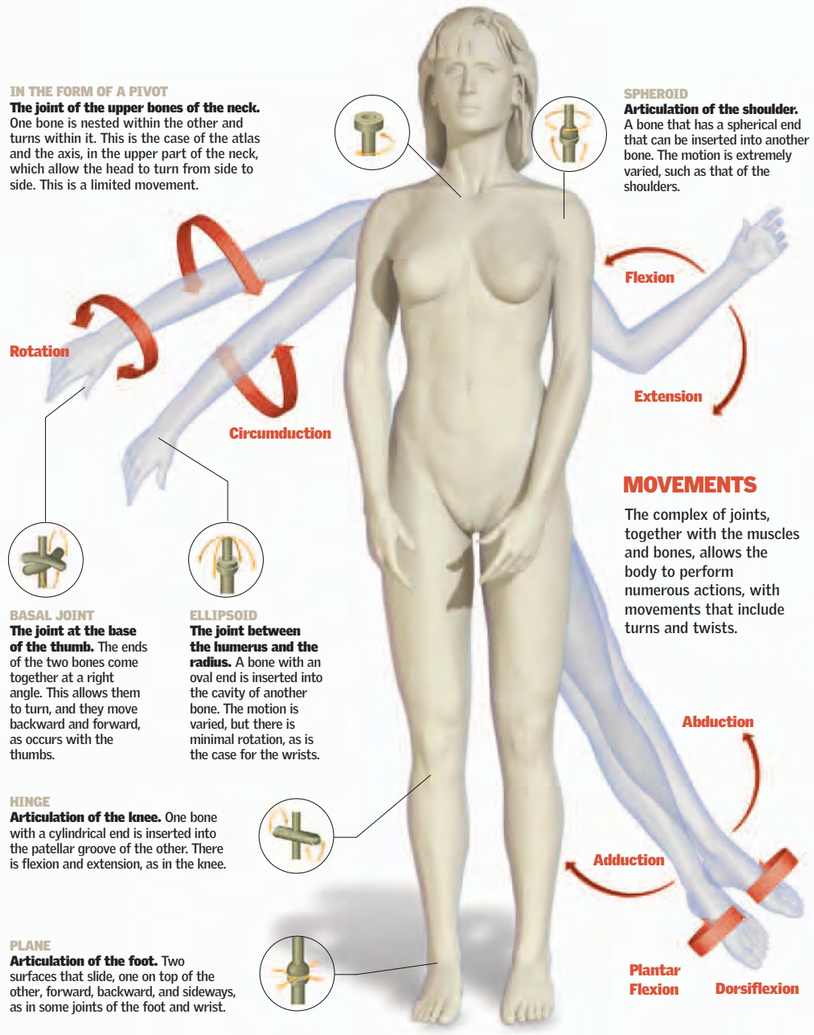
These are also called diarthroses; they are the joints with the greatest range of motion. The ends of the bones linked together are structured in various ways that facilitate their movement relative to each other, while ensuring the stability of the joint. Most joints in the body are of this type.

Semimobile

Also known as amphiarthroses. The surfaces of the bone that make contact have cartilaginous tissue. One example is the vertebral joints: they have little individual movement, but as a whole they have ample flexion, extension, and rotation.

Fixed

Also known as synarthroses. Most fixed joints are found in the cranium and have no need for motion because their primary function is to protect internal organs. They are connected by bone growth or fibrous cartilage and are extremely rigid and very tough.



MOVEMENTS

The complex of joints, together with the muscles and bones, allows the body to perform numerous actions, with movements that include turns and twists.

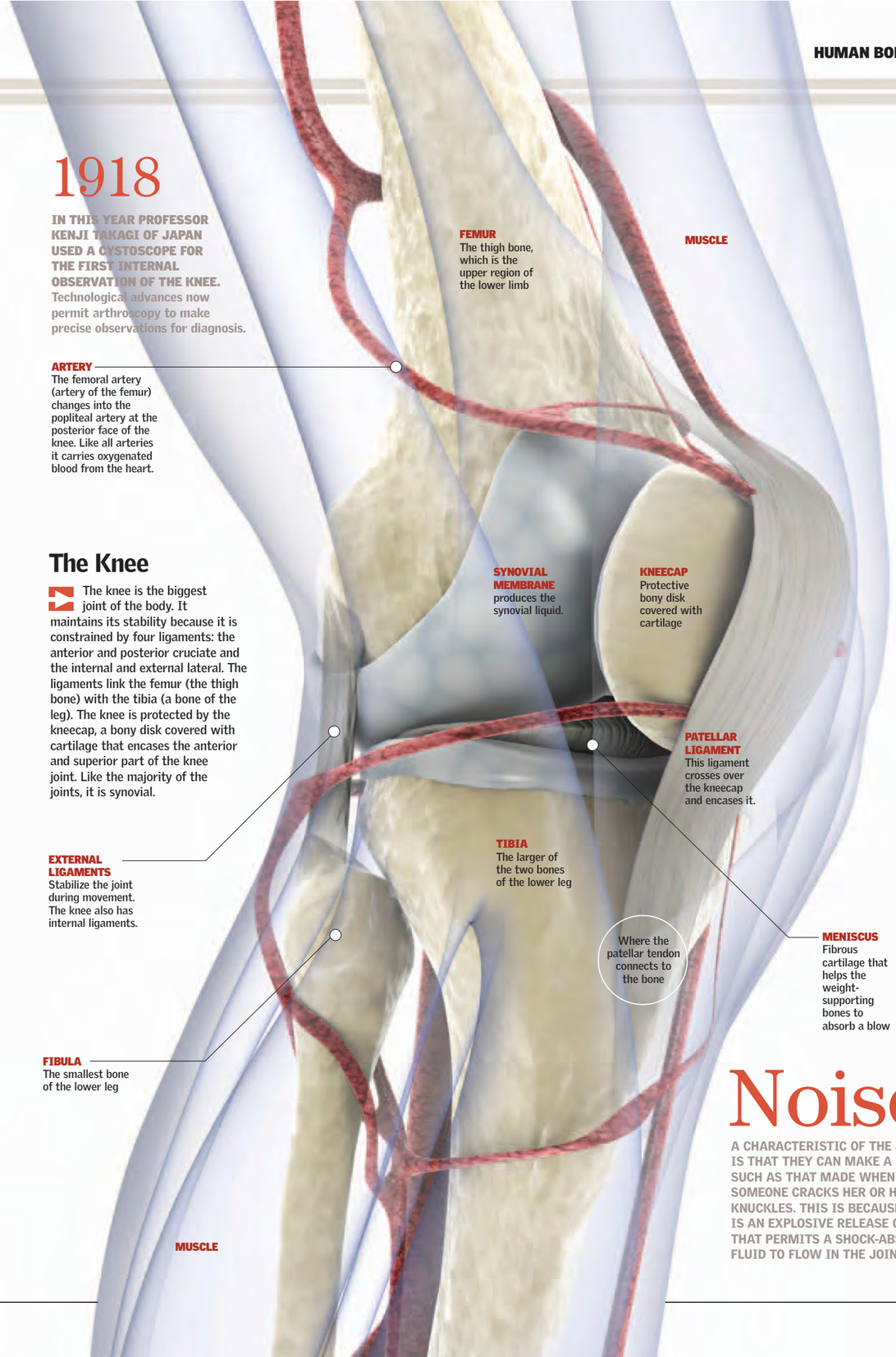
1918

IN THIS YEAR PROFESSOR KENJI TAKAGI OF JAPAN USED A CYSTOSCOPE FOR THE FIRST INTERNAL OBSERVATION OF THE KNEE. Technological advances now permit arthroscopy to make precise observations for diagnosis.

ARTERY
The femoral artery (artery of the femur) changes into the popliteal artery at the posterior face of the knee. Like all arteries it carries oxygenated blood from the heart.

The Knee

The knee is the biggest joint of the body. It maintains its stability because it is constrained by four ligaments: the anterior and posterior cruciate and the internal and external lateral. The ligaments link the femur (the thigh bone) with the tibia (a bone of the leg). The knee is protected by the kneecap, a bony disk covered with cartilage that encases the anterior and superior part of the knee joint. Like the majority of the joints, it is synovial.

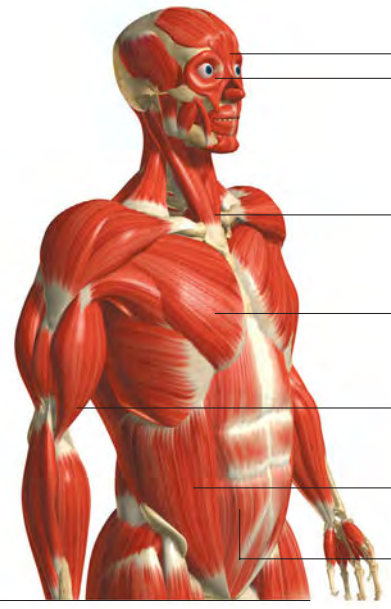


Noise

A CHARACTERISTIC OF THE JOINTS IS THAT THEY CAN MAKE A SOUND, SUCH AS THAT MADE WHEN SOMEONE CRACKS HER OR HIS KNUCKLES. THIS IS BECAUSE THERE IS AN EXPLOSIVE RELEASE OF GAS THAT PERMITS A SHOCK-ABSORBING FLUID TO FLOW IN THE JOINT.

Muscular System

The muscles are organs formed by fleshy tissue consisting of contractile cells. They are divided into striated, smooth, and, in a unique case, cardiac (the myocardium is the muscular tissue of the heart). Muscles shape and protect the organism. The muscles of the skeleton are attached to the bones to permit voluntary movement, which is consciously directed by the brain. The smooth muscles are also directed by the brain, but their motion is not voluntary, as in the case of digestion. These muscles get most of their energy from alimentary carbohydrates, which can be stored in the liver and muscles in the form of glycogen and can later pass into the blood and be used as glucose. When a person makes a physical effort, there is an increased demand for both oxygen and glucose, as well as an increase in blood circulation. A lack of glucose leads to fatigue.



FRONTAL MUSCLE
wrinkles the forehead.

ORBICULAR MUSCLE
allows blinking.

STERNOCLEIDOMASTOID
allows the head to turn and move forward.

PECTORALIS MAJOR
stretches the arm forward. It turns it and brings it close to the body.

BRACHIAL BICEP
bends the arm at the elbow.

EXTERNAL OBLIQUE
turns the trunk and bends it to both sides.

RECTUS ABDOMINIS
bends the trunk forward.

OCCIPITAL
pulls the scalp backward.

SPLENIUS
keeps the head erect.

TRAPEZIUM
turns the head and the shoulders forward. It stabilizes the shoulders.

DELTOID
A triangular muscle surrounding the shoulder. It lifts the arm to the side and causes it to swing when walking.

BRACHIAL TRICEP
stretches the arm at the elbow.

GLUTEUS MAXIMUS
extends from the hip to the thigh.

FEMORAL QUADRICEPS
A powerful muscular complex that stretches the knee when a person runs and kicks. The quadriceps include four muscles, with their upper extremes connected to the femur and the pelvis and their lower extremes anchored in the tibia. When the muscles contract, the lower part of the leg is thrust forward.

FEMORAL BICEP
bends the leg at the knee.

GASTROCNEMIUS
Also called "twins." There are two, and they extend from the femur to the calcaneus. They bend the leg.

ANTERIOR TIBIA
lifts the foot and is connected to the metatarsal bones of the foot.

EXTENSOR DIGITORUM LONGUS
Called the "pedis," it connects to the dorsal part of the foot.

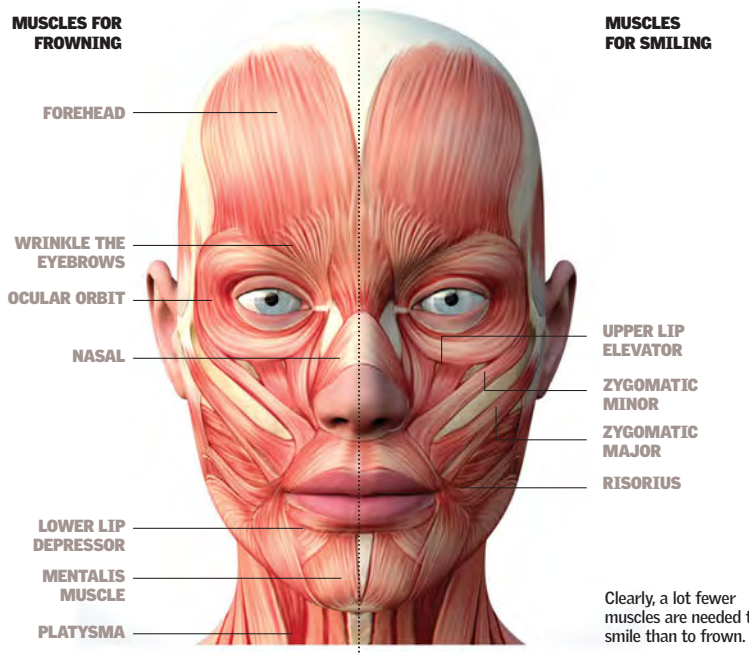
ACHILLES TENDON
connects the gastrocnemius to the calcaneus bone (talus bone).

When the Skeleton Moves

The great number of muscles of voluntary action available to the human body makes possible thousands of distinct movements. Actions from the simple blink of an eyelid to the twisting of a belt are accomplished by muscular action. The eye muscles involve the most activity because they carry out 100,000 movements per day. Some 30 muscles control all the movements of the face and define an infinite possible combination of facial expressions. It is calculated that to pronounce one word, the organs for speech and respiration move some 70 muscles. The stirrup muscle, which controls the stirrup of the ear, is one of the smallest in the body. It measures approximately 0.05 inch (1.2 mm). There are other muscles that are very large, including the latissimus dorsi of the shoulder. The foot has 40 muscles and more than 200 ligaments. Because the muscles are connected by a great number of nerves, a lesion or blow causes the brain to react, producing pain. Approximately 40 percent of the total weight of the body consists of the muscular system. When the organism reduces the quantity of calories it normally ingests (for example, when a person goes on a diet), the first thing the body loses is water, which is reflected in a rapid weight loss. Then the metabolism adapts to the diet, and the body resorts to using up muscle tissue before drawing on the fats stored for burning calories. For this reason, when the diet begins this second phase, the consequences can be lack of vigor and loss of muscle tone, which is recovered when the diet returns to normal.

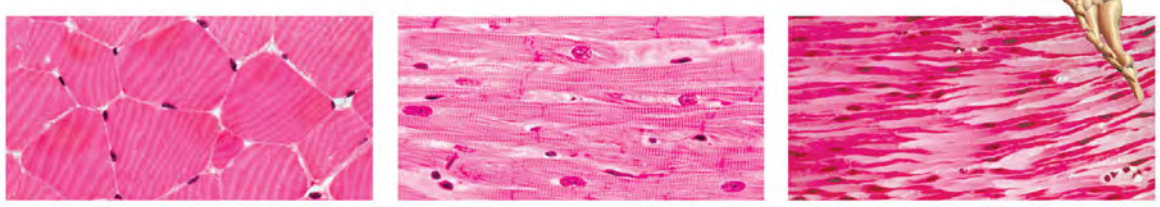
650 skeletal muscles

OR VOLUNTARY MUSCLES ARE IN THE TYPICAL HUMAN BODY.



Clearly, a lot fewer muscles are needed to smile than to frown.

THE THREE TYPES OF MUSCLES



STRIATED
They are also called "skeletal" (because they cover the skeleton) and "voluntary." They are composed of cells and fibers that contract rapidly.

CARDIAC
Composed of small interconnected fibers, which maintain the rhythmic and continuous pumping of the heart.

SMOOTH
Perform unconscious actions such as digestion. Their fibers contract slowly over an extended period of time.

Muscular Fiber

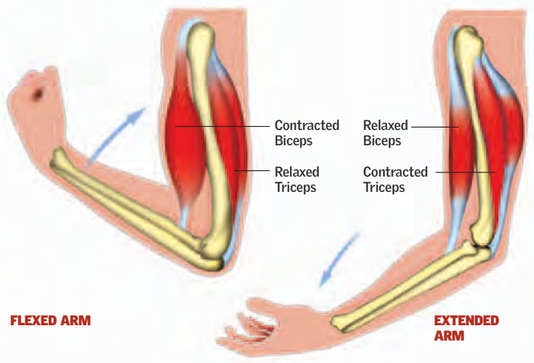
A fiber is the long, thin cell that, when organized by the hundreds into groups called fascicles, constitutes the muscles. It is shaped like an elongated cylinder. The amount of fiber present varies according to the function accomplished by each muscle. Fibers are classified as white, which contract readily for actions that require force and power, and red, which perform slow contractions in movements of force and sustained traction. Each muscle fiber contains in its structure numerous filaments called myofibers. Myofibers, in turn, have two classes of protein filaments: myosin, also called thick filaments, and actin, or thin filaments. Both kinds of fibers are arranged in tiny matrices called sarcomeres.

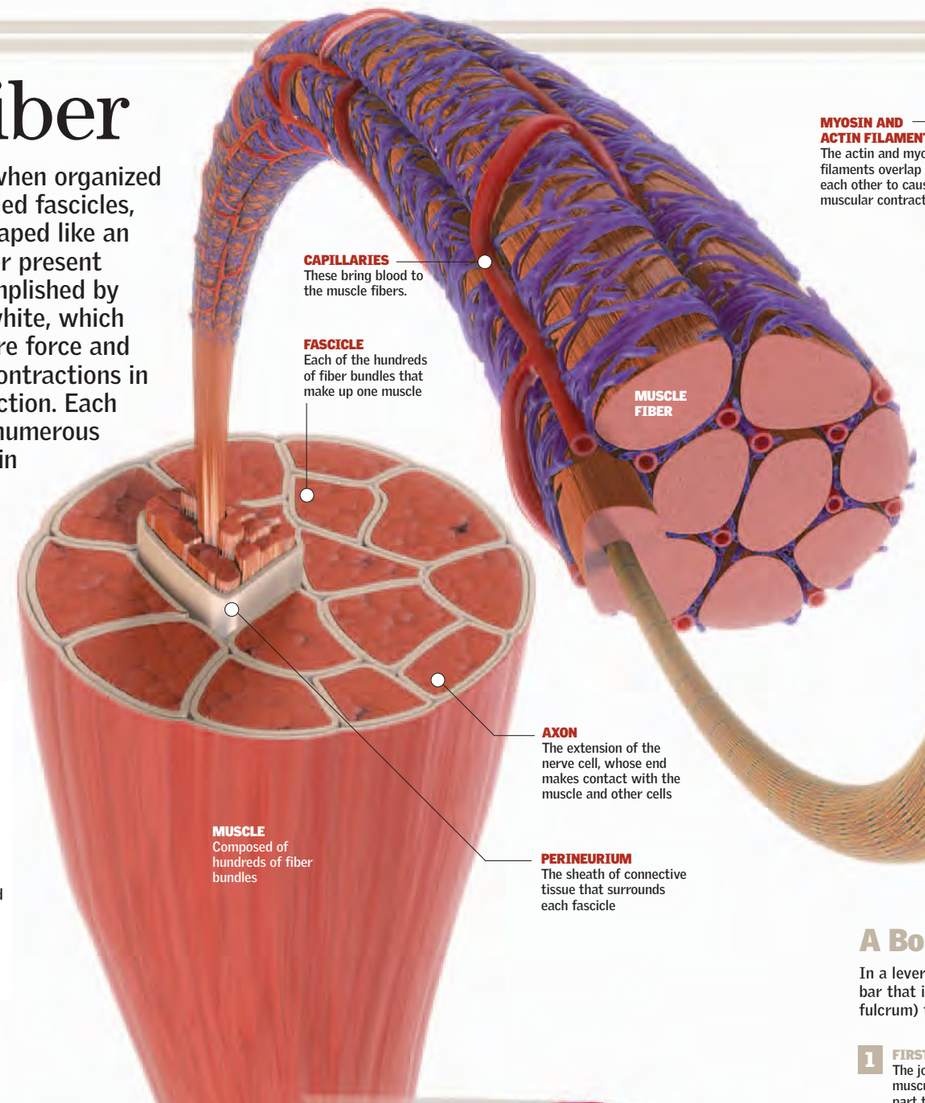
Specialization

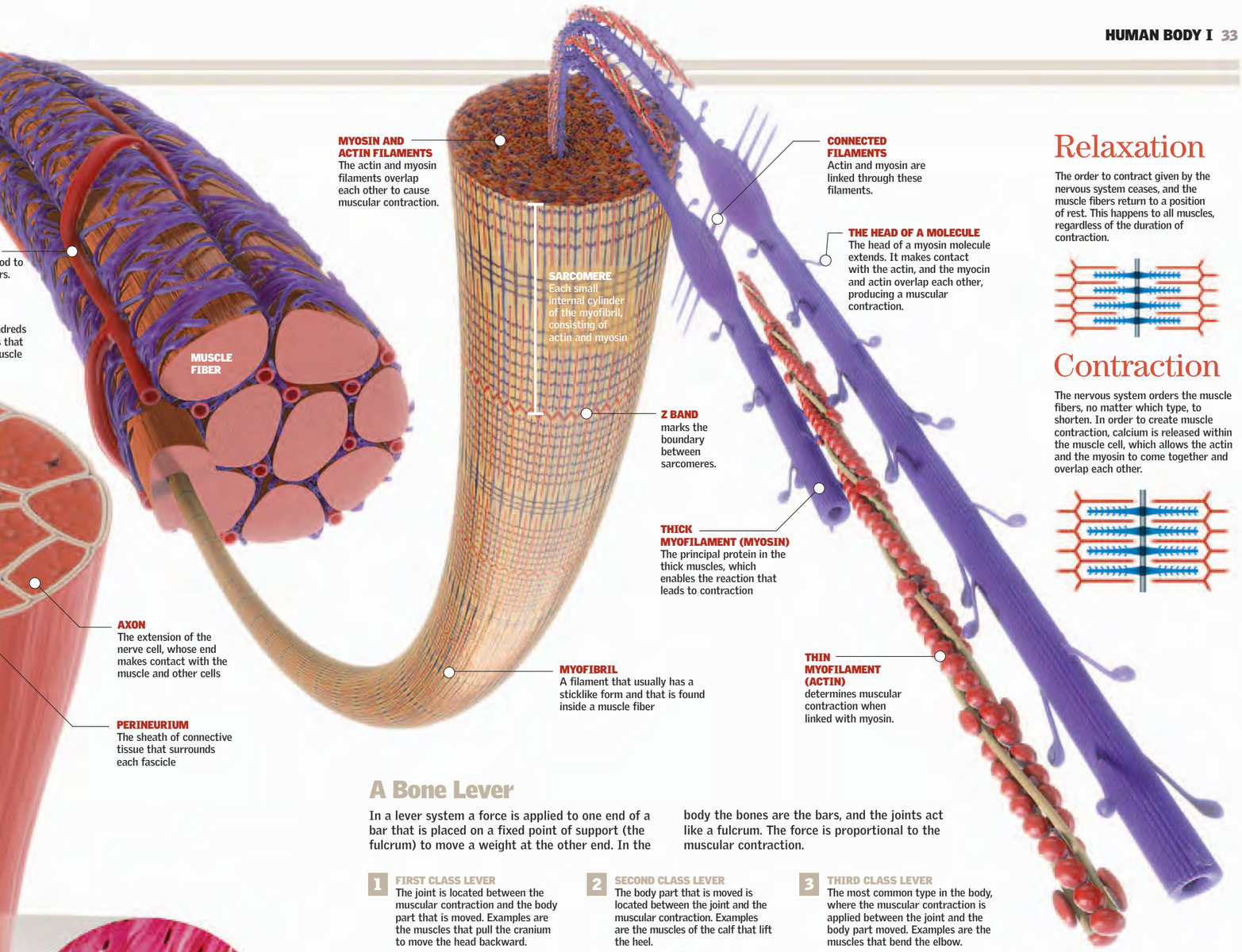
The quantity of muscle fiber varies according to the size and function of the muscle. Also, the same muscle can combine white fibers (rapid contracters) and red fibers (slow contracters). Even though their percentages differ from one person to the next, the composition of the muscles of the upper limbs tends to be the same as that of the lower in the same person. In other words, the relation between motor neurons and muscle fibers is inscribed in a person's genes. Depending on the type of neuron that stimulates them, the fibers are differentiated into slow fibers (when the neuron or motor neuron innervates between five and 180 fibers) and rapid fibers (when the neuron innervates between 200 and 800 fibers). The neurons and the fiber constitute what is called a motor unit.

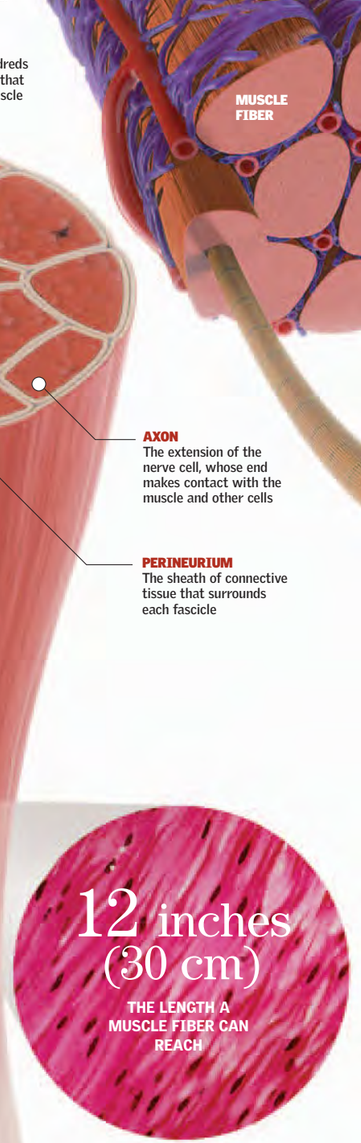
Opposites

The muscles contract or relax according to the movement to be accomplished. To make the brain's directive take effect, the muscles involved carry out opposing actions.









Relaxation

The order to contract given by the nervous system ceases, and the muscle fibers return to a position of rest. This happens to all muscles, regardless of the duration of contraction.

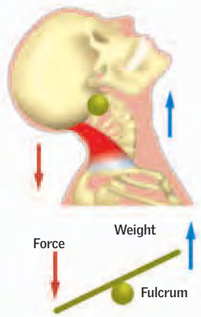
Contraction

The nervous system orders the muscle fibers, no matter which type, to shorten. In order to create muscle contraction, calcium is released within the muscle cell, which allows the actin and the myosin to come together and overlap each other.

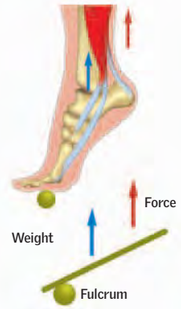
A Bone Lever

In a lever system a force is applied to one end of a bar that is placed on a fixed point of support (the fulcrum) to move a weight at the other end. In the body the bones are the bars, and the joints act like a fulcrum. The force is proportional to the muscular contraction.

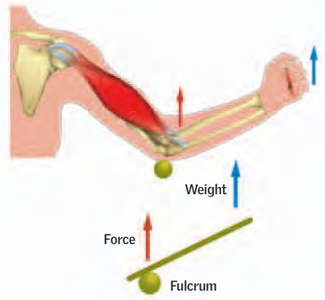
1 FIRST CLASS LEVER
The joint is located between the muscular contraction and the body part that is moved. Examples are the muscles that pull the cranium to move the head backward.



2 SECOND CLASS LEVER
The body part that is moved is located between the joint and the muscular contraction. Examples are the muscles of the calf that lift the heel.



3 THIRD CLASS LEVER
The most common type in the body, where the muscular contraction is applied between the joint and the body part moved. Examples are the muscles that bend the elbow.



70%

THE POTENTIAL CONTRACTION OF A MUSCLE FIBER IN TERMS OF THE FIBER'S LENGTH

Running

Marathon runners may have as much as 90 percent red, or slow, fibers in their twin muscles. Champions in the 100-meter dash have only 20 to 25 percent.

Internal Systems and Organs

THE CHEMISTRY OF LOVE
Even a light kiss results in the release of adrenaline, causing a sensation of euphoria and joy.

CIRCULATORY SYSTEM 36-37
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URINARY SYSTEM 58-59
KIDNEYS 60-61
ENDOCRINE SYSTEM 62-63
MALE REPRODUCTIVE SYSTEM 64-65
FEMALE REPRODUCTIVE SYSTEM 66-67

It is difficult to explain that the sexual attraction between a man and woman—something that appears to be so natural and intimate—is a chemical phenomenon. What is certain is that when a couple feels they are in love, it is because hormones have gone into action. Without them, amorous thoughts and sexual fantasies would be drab and dull. We invite you to find out to what extent hormones determine many of our actions and also to investigate in detail, one by one, how the body's systems function. You will learn to understand how various organs of the body work as a team. Although each organ accomplishes specific tasks on its own, they all communicate with each other, and together they form a complete human being. ●

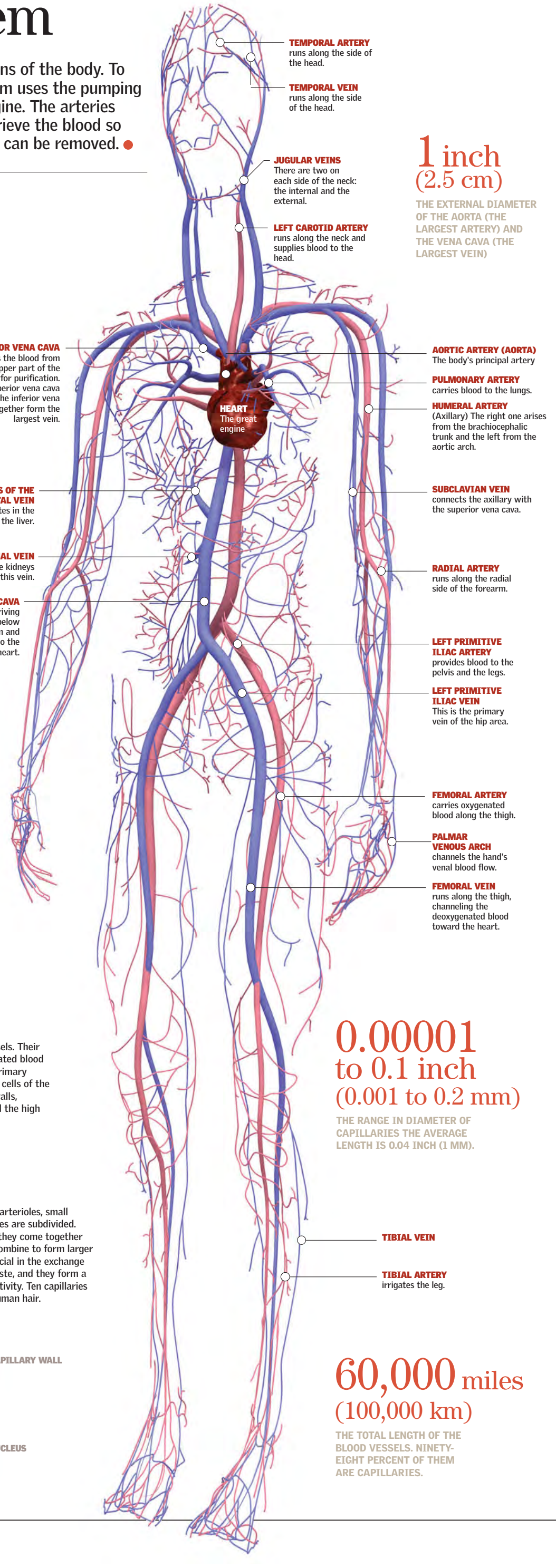
Circulatory System

Its function is to carry blood to and from all the organs of the body. To drive the constant movement of the blood, the system uses the pumping of the heart, the organ that acts as the system's engine. The arteries bring oxygen-rich blood to all the cells, and the veins retrieve the blood so that it can be oxygenated once again and so that wastes can be removed.

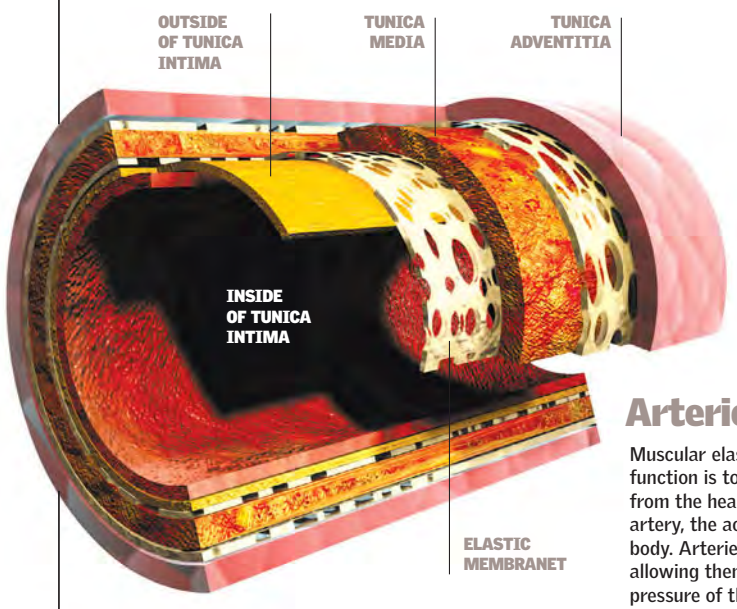
A System That Goes Around

The center of the system is the heart, which, together with a network of vessels, forms the cardiovascular machinery. This vital engine beats more than 30 million times a year-approximately 2 billion times in a person's lifetime. With each beat it pumps about 5 cubic inches (82 ml) of blood. This means that an adult heart could fill a 2,000-gallon (8,000-l) tank in just one day. Beginning at the heart, the circulatory system completes two circuits: the main, or systemic, circulation via the aortic artery and the minor, or pulmonary, circulation. The main circulation brings oxygenated blood to the capillary system, where the veins are formed; the minor circulation brings oxygen-poor blood through the pulmonary artery to be enriched with oxygen and to have carbon dioxide removed from it, a process called hematosis. Other secondary circuits are the hepatic portal system and the hypophyseal portal system.

BLOOD DISTRIBUTION DURING CIRCULATION



1 inch (2.5 cm)
THE EXTERNAL DIAMETER OF THE AORTA (THE LARGEST ARTERY) AND THE VENA CAVA (THE LARGEST VEIN)

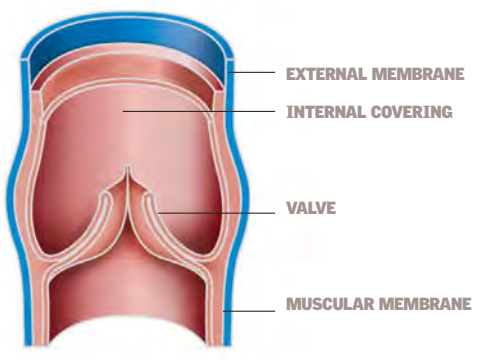


Arteries

Muscular elastic blood vessels. Their function is to bring oxygenated blood from the heart (from the primary artery, the aorta) to all the cells of the body. Arteries have thick walls, allowing them to withstand the high pressure of the blood.

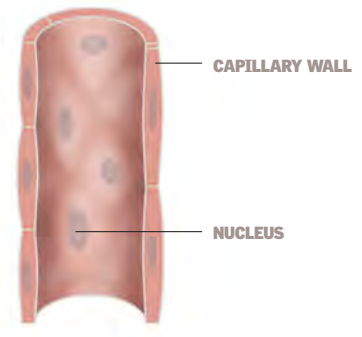
Veins

The veins are the conduits that transport deoxygenated blood back toward the heart after it has traveled to different parts of the body. The veins have thin walls with less muscular fiber and less elasticity than the arteries. The principal veins have valves to prevent the reflux of blood, forcing it to travel in only one direction.



Capillaries

These are branchings of the arterioles, small vessels into which the arteries are subdivided. The capillaries are tiny, and they come together to form small veins, which combine to form larger veins. The capillaries are crucial in the exchange of oxygen, nutrients, and waste, and they form a network to carry out this activity. Ten capillaries together are as thick as a human hair.



0.00001 to 0.1 inch (0.001 to 0.2 mm)
THE RANGE IN DIAMETER OF CAPILLARIES THE AVERAGE LENGTH IS 0.04 INCH (1 MM).

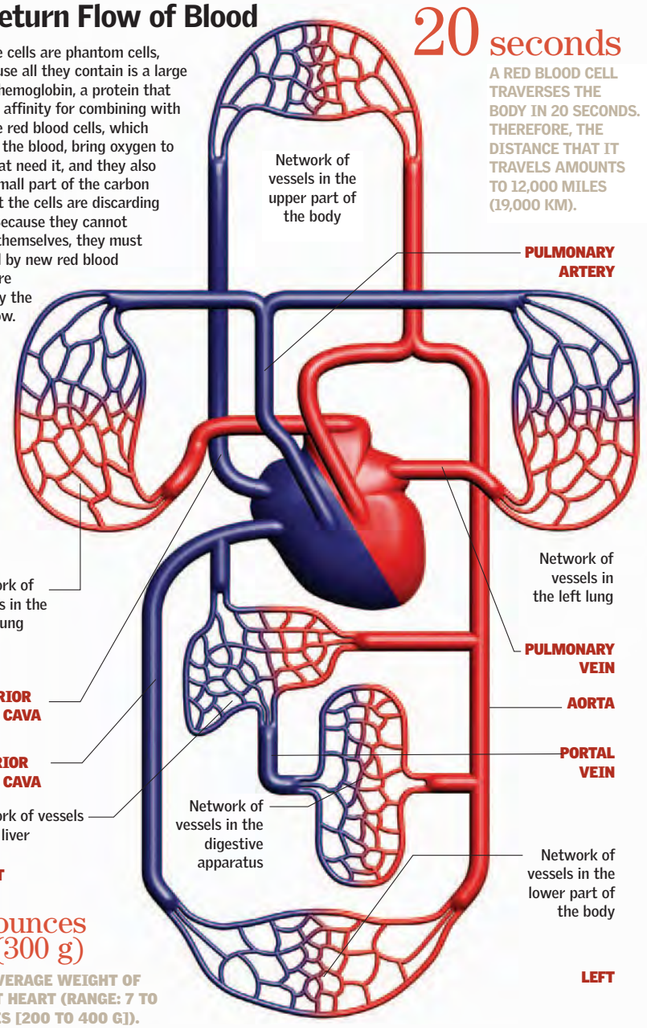
60,000 miles (100,000 km)
THE TOTAL LENGTH OF THE BLOOD VESSELS. NINETY-EIGHT PERCENT OF THEM ARE CAPILLARIES.

All About the Heart

The heart is the engine of the circulatory apparatus: it supplies 10 pints (4.7 l) of blood per minute. Its rhythmic pumping ensures that blood arrives in every part of the body. The heart beats between 60 and 100 times per minute in a person at rest and up to 200 times per minute during activity. The heart is a hollow organ, the size of a fist; it is enclosed in the thoracic cavity in the center of the chest above the diaphragm. The name of the stomach's entrance, or cardias, comes from the Greek word for heart, *kardia*. Histologically, one can distinguish three layers of tissue in the heart, starting from the inside out: the endocardium, the myocardium, and the pericardium.

The Return Flow of Blood

These cells are phantom cells, because all they contain is a large amount of hemoglobin, a protein that has a great affinity for combining with oxygen. The red blood cells, which circulate in the blood, bring oxygen to the cells that need it, and they also remove a small part of the carbon dioxide that the cells are discarding as waste. Because they cannot reproduce themselves, they must be replaced by new red blood cells that are produced by the bone marrow.



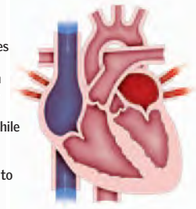
20 seconds

A RED BLOOD CELL TRAVERSES THE BODY IN 20 SECONDS. THEREFORE, THE DISTANCE THAT IT TRAVELS AMOUNTS TO 12,000 MILES (19,000 KM).

10 ounces (300 g)

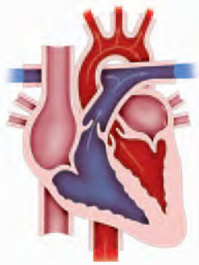
IS THE AVERAGE WEIGHT OF AN ADULT HEART (RANGE: 7 TO 14 OUNCES [200 TO 400 G]).

THE SEQUENCE OF THE HEARTBEAT



1 DIASTOLIC
The atria and the ventricles are relaxed. The blood, supercharged with carbon dioxide, flows from all the corners of the body and enters the right atrium, while the blood that was oxygenated through the work of the lungs returns to the left part of the heart.

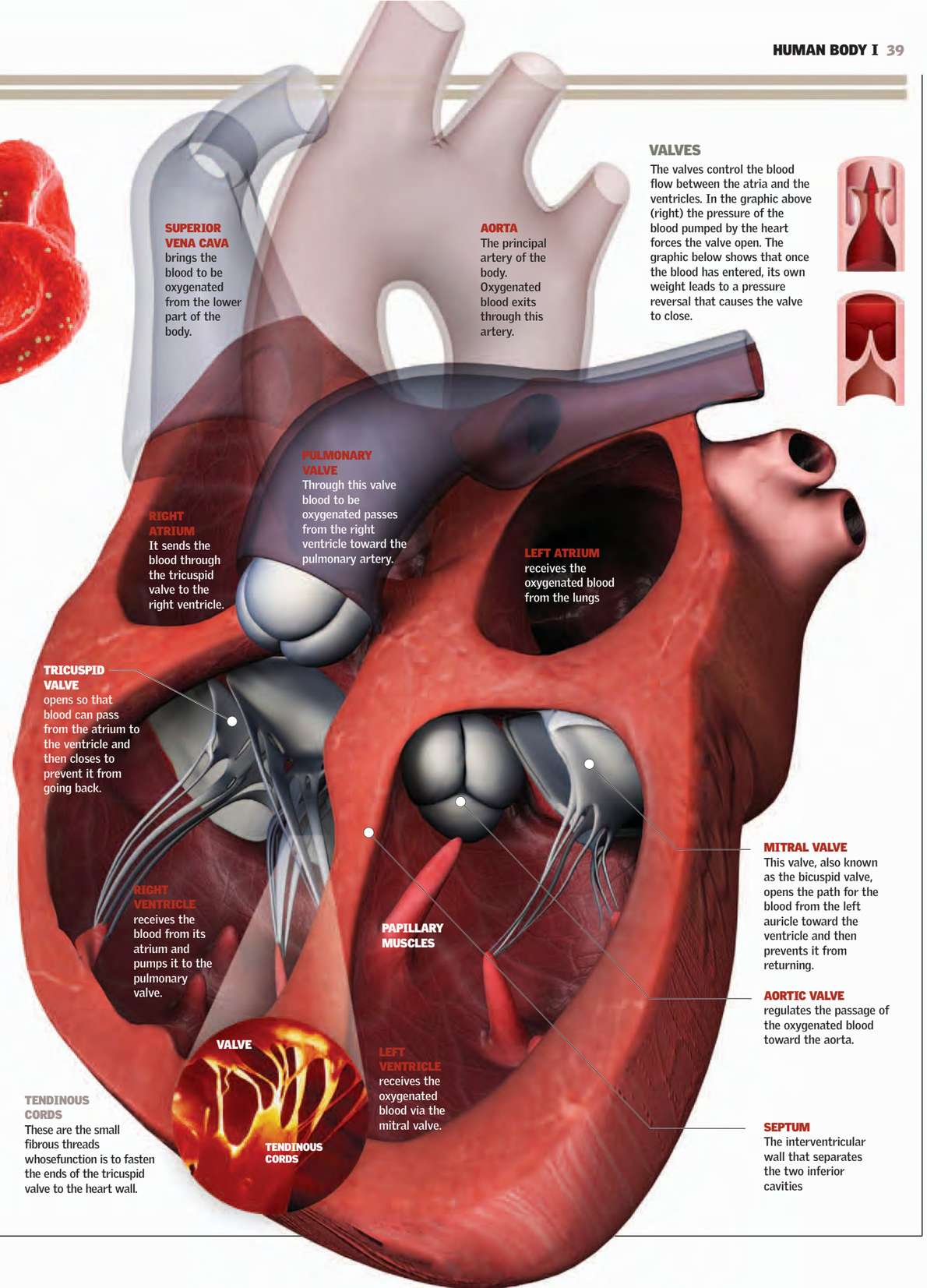
2 ATRIAL SYSTOLE
The atria contract to push the blood down toward the ventricles. The right ventricle receives the blood that will have to be sent to the lungs to be oxygenated. The left ventricle receives blood coming from the lungs, which is already oxygenated and must be pumped toward the aorta.



3 VENTRICULAR SYSTOLE
The ventricles contract after a brief pause. The systole, or contraction, of the right ventricle sends impure blood to the lungs. The contraction of the left ventricle pumps the already oxygenated blood toward the aorta; it is ready for distribution throughout the body.

70

IS THE APPROXIMATE NUMBER OF TIMES THAT THE HEART BEATS PER MINUTE. IT PUMPS 2,000 GALLONS (8,000 L) OF BLOOD PER DAY.



Components of the Blood

The blood is a liquid tissue composed of water, dissolved substances, and blood cells. The blood circulates inside the blood vessels thanks to the impulse it receives from the contraction of the heart. A principal function of the blood is to distribute nutrients to all the cells of the body. For example, the red blood cells (erythrocytes) carry oxygen, which associates with the hemoglobin, a substance in the cell responsible for the blood's red color. The blood also contains white blood cells and platelets that protect the body in various ways.

1

Red Blood Cells

These cells are phantom cells, because all they contain is a large amount of hemoglobin, a protein that has a great affinity for combining with oxygen. The red blood cells, which circulate in the blood, bring oxygen to the cells that need it, and they also remove a small part of the carbon dioxide that the cells are discarding as waste. Because they cannot reproduce themselves, they must be replaced by new red blood cells that are produced by the bone marrow.

FLEXIBILITY
Red blood cells are flexible and take on a bell shape in order to pass through the thinnest blood vessels.

5 quarts (4.7 l)
THE APPROXIMATE VOLUME OF BLOOD PRESENT IN A HUMAN ADULT

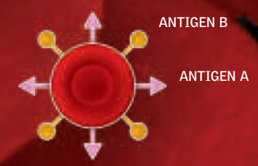
The Blood Groups

Each person belongs to a blood group. Within the ABO system the groups are A, B, AB, and O. Each group is also identified with an antigen, or Rh factor, that is present in the red blood cells of 85 percent of the population. It is of vital importance to know what blood group a person belongs to so as to give only the right type during a blood transfusion. The immune system, via antibodies and antigens, will accept the body's own blood type but will reject the wrong type.

GROUP A
An individual with red blood cells with antigen A in its membranes belongs to blood group A, and that person's plasma has antibodies against type B. These antibodies recognize red blood cells with antigen B in their membranes as foreign.

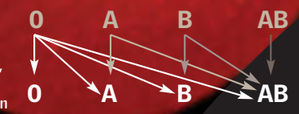
GROUP B
Members of this group have antigen B in the membrane of their red blood cells and anti-A antibodies in their blood plasma.

GROUP AB
Members of this group have antigen A and B in the membrane of their red blood cells and no antibodies in their blood plasma.



GROUP O
Members of this group have no antigens in the membranes of their erythrocytes and anti-A and anti-B antibodies in their blood plasma

COMPATIBILITY
Donors of group O can give blood to any group, but group AB donors can give only to others with AB blood. The possibility of blood donation depends on the antibodies of the recipient.



2

White Blood Cells, or Leukocytes

This is what a leukocyte, or white blood cell, looks like swimming in blood plasma. They are called white because that is their color when viewed under a microscope.

7%
IS THE PORTION OF BODY WEIGHT REPRESENTED BY THE BLOOD.

COMPOSITION

GRANULOCYTES	Neutrophils
	Eosinophils
	Basophils
AGRANULOCYTES	Lymphocytes
	Monocytes

Blood Components

The blood is a tissue, and as such it is characterized by the same type of cells and intercellular substance as tissue. It is distinguished from the rest of the tissues in the human body by an abundance of intercellular material, which consists primarily of water. The intercellular material, called plasma, is yellow, and it contains abundant nutrients and other substances, such as hormones and antibodies, that take part in various physiological processes.

COMPONENTS OF THE BLOOD PER 0.00006 cubic inch (1 cu ml)

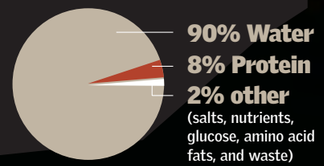
Red Blood Cells	4 to 6 million
White Blood Cells	4,500 to 11,000
Platelets	150,000 to 400,000
Normal pH	7.40

DAILY PRODUCTION IN MILLIONS

4

Plasma

Red and white blood cells and platelets (which contribute to coagulation) make up 45 percent of the blood. The remaining 55 percent is plasma, a fluid that is 90 percent water and the rest various nutrients.



3

Platelets

are cell fragments that have separated from the megakaryocytes, cells located in the bone marrow. They have a role in blood coagulation. Next to the red blood cells, the platelets are the most abundant component of the blood.

98.6° F (37° C)
THE BLOOD MAINTAINS THE BODY AT THIS AVERAGE TEMPERATURE.

0.0003 INCH (0.008 MM)

Lymphatic System

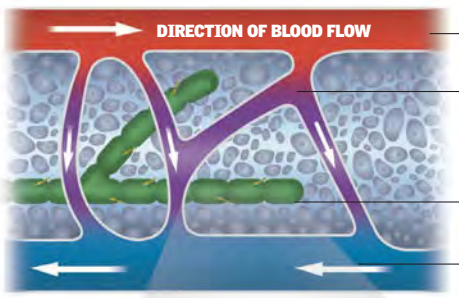
It accomplishes two basic functions: defense against foreign organisms (such as bacteria) and aid with transport of liquid and matter via the circulation of the lymph from the interstices of the tissue and from the digestive apparatus to the blood. About 3 to 4 quarts (2.8-3.7 l) of the liquid circulating in the system do not return. This liquid is known as lymph, and it is reabsorbed into the plasma only through the lymphatic vessels. The lymph contains cells called lymphocytes and macrophages, which are part of the immune system.

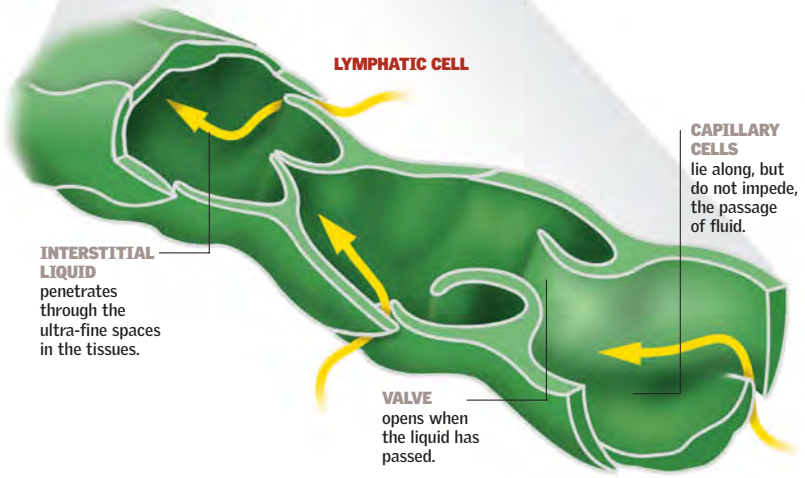
Lymphatic Network

This network contains vessels that extend throughout the body and that filter the liquid that comes from the area surrounding the cells. The lymph circulates in only one direction and returns to the blood through the walls of small blood vessels. There are valves that prevent the lymph from flowing in the opposite direction. The lymph nodes filter harmful microorganisms from the lymph, which returns via blood vessels to maintain the equilibrium of the body's fluids. Together with the white blood cells, the lymph nodes are in charge of maintaining the immune system.

Lymphatic Tissue

One part of the liquid that exits from blood flow and distributes itself in the body returns only through the action of the lymphatic tissue, which reabsorbs it via the lymphatic capillaries and returns it to the blood via the lymphatic vessels.



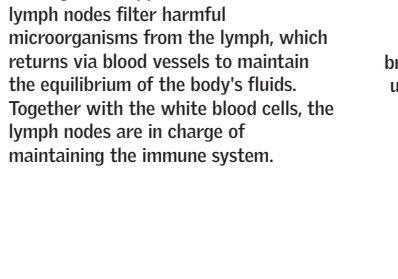


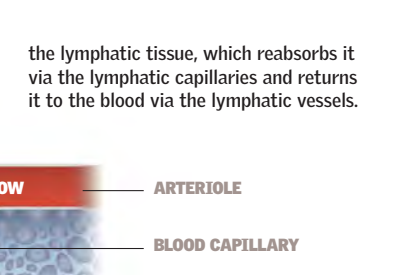
Immune Response

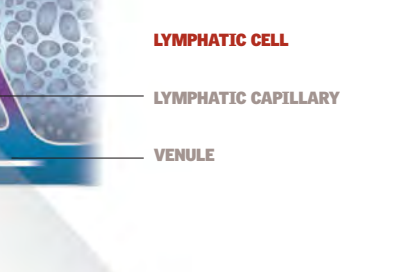
1. The lymphatic system generates lymphocytes (also found in the blood and in other tissue) and macrophages. Together they constitute the immune system. Here invading bacteria are devoured by a macrophage, and the B lymphocytes take information from the surface of the bacteria that they need to "recognize" other similar bacteria.

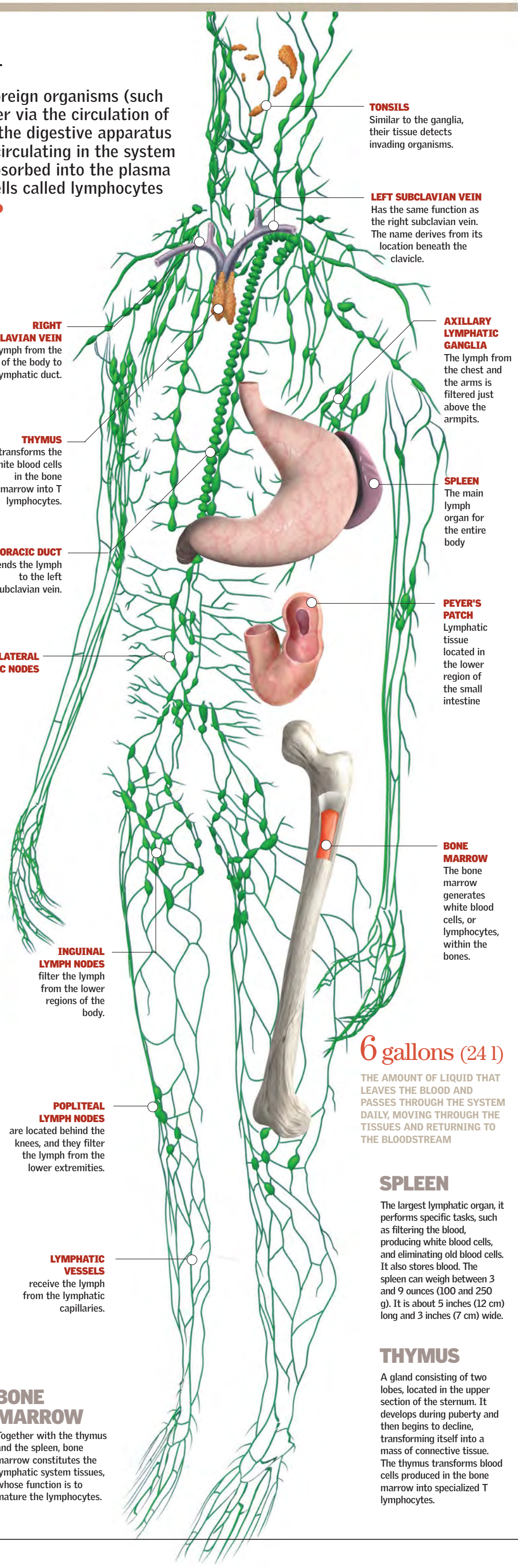
2. The B lymphocytes are activated and upon recognizing a pathogen divide themselves into plasmatic cells and memory cells. The plasmatic cells secrete thousands of antibody molecules per second, which are carried by the blood to the site of the infection. The memory cells retain the antigen information, and, when faced with a new invasion, will once again divide rapidly in order to deal with it.

3. The antibodies, also called "immunoglobin," are protein molecules in the form of a "Y," with arms unique to each specific type of antibody. It is this feature that attaches them to a specific antigen. Their function is to "mark" invaders, which can then be destroyed by the macrophages.









BONE MARROW

Together with the thymus and the spleen, bone marrow constitutes the lymphatic system tissues, whose function is to mature the lymphocytes.

6 gallons (24 l)

THE AMOUNT OF LIQUID THAT LEAVES THE BLOOD AND PASSES THROUGH THE SYSTEM DAILY, MOVING THROUGH THE TISSUES AND RETURNING TO THE BLOODSTREAM

SPLEEN

The largest lymphatic organ, it performs specific tasks, such as filtering the blood, producing white blood cells, and eliminating old blood cells. It also stores blood. The spleen can weigh between 3 and 9 ounces (100 and 250 g). It is about 5 inches (12 cm) long and 3 inches (7 cm) wide.

THYMUS

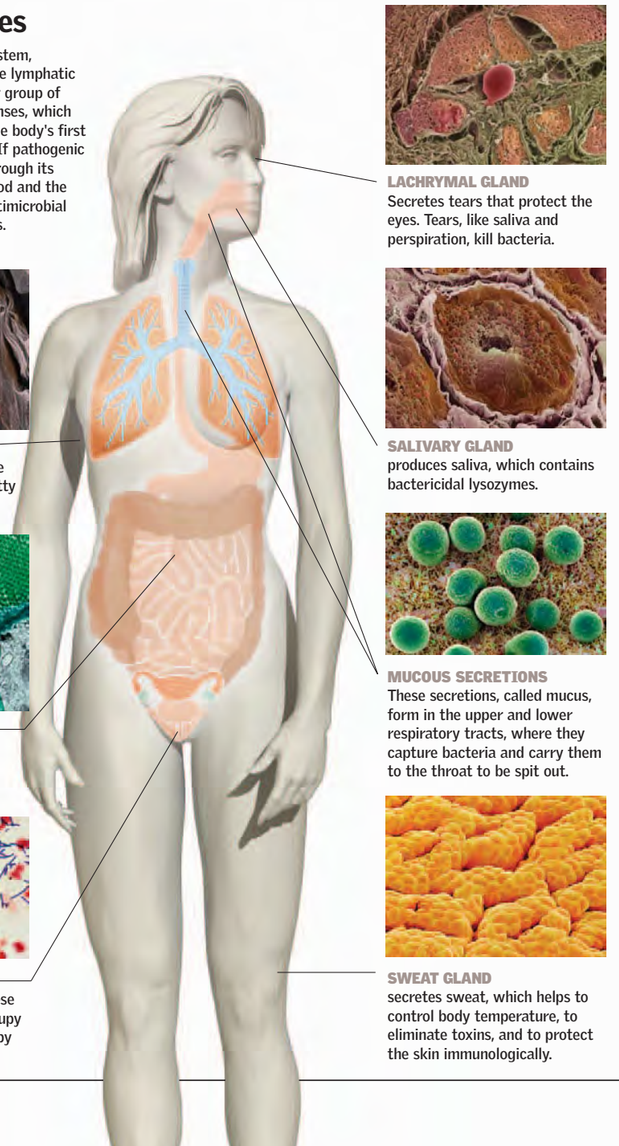
A gland consisting of two lobes, located in the upper section of the sternum. It develops during puberty and then begins to decline, transforming itself into a mass of connective tissue. The thymus transforms blood cells produced in the bone marrow into specialized T lymphocytes.

Lymph Node

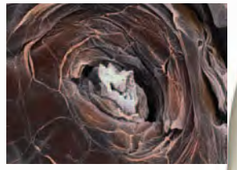
Also called a lymph gland, this node has a round shape and is about 0.4 inch (1 cm) in diameter. Lymph nodes are distributed throughout the body—in the neck, armpits, groin, and popliteal bone (behind the knees), as well as in the thorax and abdomen. The lymphatic vessels are the ducts for the lymph and the pathways for communication among the lymph nodes. The battle of the immune system against invading germs takes place within the nodes, which then enlarge because of inflammation.

Natural Defenses

Besides the immune system, composed in part by the lymphatic system, the body has another group of resources called natural defenses, which people possess from birth. The body's first defensive barrier is the skin. If pathogenic agents succeed in passing through its filters, however, both the blood and the lymph possess specialized antimicrobial cells and chemical substances.

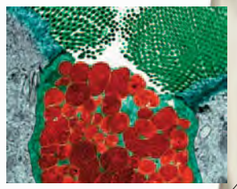


LACHRYMAL GLAND
Secretes tears that protect the eyes. Tears, like saliva and perspiration, kill bacteria.



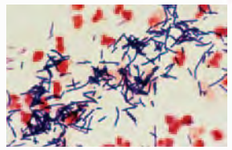
SEBACEOUS GLAND
Located on the surface of the skin, this gland secretes a fatty substance called sebo.

SALIVARY GLAND
produces saliva, which contains bactericidal lysozymes.



INTESTINAL MUCOSA
The goblet cells in this membrane produce a defensive mucus.

MUCOUS SECRETIONS
These secretions, called mucus, form in the upper and lower respiratory tracts, where they capture bacteria and carry them to the throat to be spit out.



VAGINAL BACTERIA
Under normal conditions, these are inoffensive, and they occupy areas that could be invaded by pathogenic bacteria.

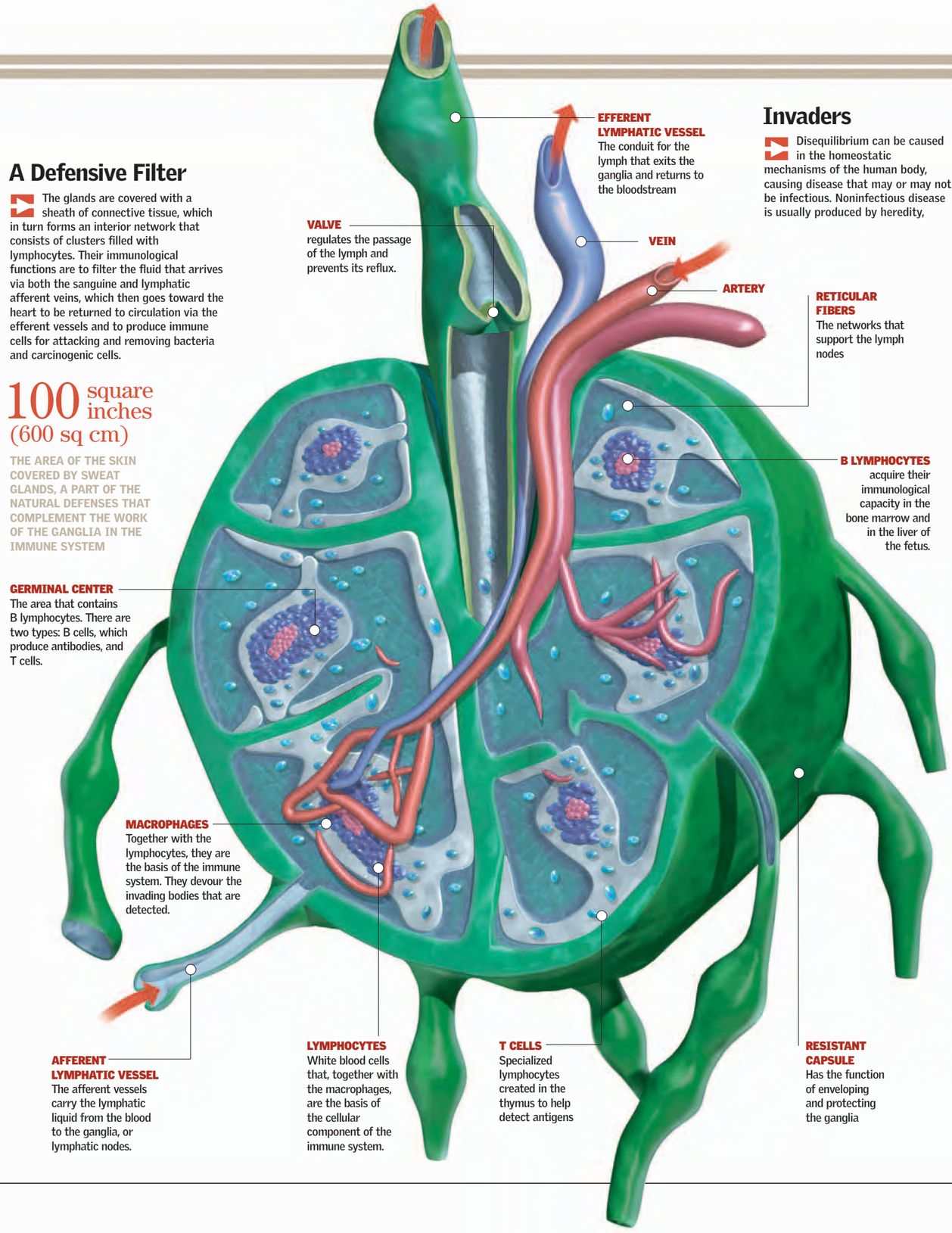
SWEAT GLAND
secretes sweat, which helps to control body temperature, to eliminate toxins, and to protect the skin immunologically.

A Defensive Filter

The glands are covered with a sheath of connective tissue, which in turn forms an interior network that consists of clusters filled with lymphocytes. Their immunological functions are to filter the fluid that arrives via both the sanguine and lymphatic afferent veins, which then goes toward the heart to be returned to circulation via the efferent vessels and to produce immune cells for attacking and removing bacteria and carcinogenic cells.

100 square inches (600 sq cm)

THE AREA OF THE SKIN COVERED BY SWEAT GLANDS, A PART OF THE NATURAL DEFENSES THAT COMPLEMENT THE WORK OF THE GANGLIA IN THE IMMUNE SYSTEM



EFFERENT LYMPHATIC VESSEL
The conduit for the lymph that exits the ganglia and returns to the bloodstream

VALVE
regulates the passage of the lymph and prevents its reflux.

VEIN

ARTERY

RETICULAR FIBERS
The networks that support the lymph nodes

B LYMPHOCYTES
acquire their immunological capacity in the bone marrow and in the liver of the fetus.

GERMINAL CENTER
The area that contains B lymphocytes. There are two types: B cells, which produce antibodies, and T cells.

MACROPHAGES
Together with the lymphocytes, they are the basis of the immune system. They devour the invading bodies that are detected.

AFFERENT LYMPHATIC VESSEL
The afferent vessels carry the lymphatic liquid from the blood to the ganglia, or lymphatic nodes.

LYMPHOCYTES
White blood cells that, together with the macrophages, are the basis of the cellular component of the immune system.

T CELLS
Specialized lymphocytes created in the thymus to help detect antigens

RESISTANT CAPSULE
Has the function of enveloping and protecting the ganglia

Invaders

Disequilibrium can be caused in the homeostatic mechanisms of the human body, causing disease that may or may not be infectious. Noninfectious disease is usually produced by heredity, external factors, or lifestyle. Infections are brought on by parasitic organisms, such as bacteria, viruses, fungi, and protozoa (single-celled organisms belonging to the protist kingdom).

A BACTERIA
are found by the billions in any medium. Not all of them are harmful. Bacteria known as germs are pathogenic and release poisonous substances called toxins.

B VIRUSES
are not really living beings but chemical packages. They consist of genetic material. When they enter the body, they invade a cell, where they reproduce and then spread.

C PROTOZOA
are organisms that typically live in water and in soil. There are about 30 pathogenic species, which can produce a range of diseases from sleeping sickness and severe diarrhea to malaria.

Red

THE COLOR OF INFLAMED SKIN WHEN BACTERIAL ACTION IN A WOUND CAUSES VASODILATION. THIS OCCURS BECAUSE THE BLOOD VESSELS EXPAND TO INCREASE BLOOD FLOW AS A MEANS OF DEFENSE.

Respiratory System

The respiratory system organizes and activates respiration, a process by which the human body takes in air from the atmosphere, extracts the oxygen that the circulation will bring to all the cells, and returns to the air products it does not need, such as carbon dioxide. The basic steps are inhalation, through which air enters the nose and mouth, and exhalation, through which air is expelled. Both actions are usually involuntary and automatic. Respiration involves the airway that begins in the nose and continues through the pharynx, larynx, trachea, bronchi, bronchioles, and alveoli; however, respiration occurs primarily in the two lungs, which are essentially bellows whose job it is to collect oxygen from the air. The oxygen is then distributed to the entire body via the blood.

6 quarts (5.5 l)

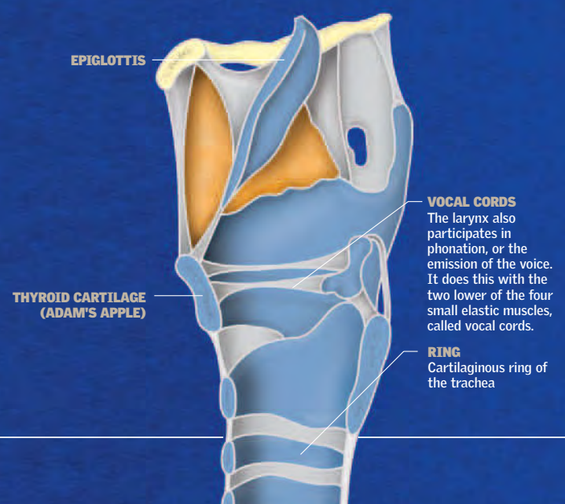
THE APPROXIMATE VOLUME OF AIR THAT ENTERS AND EXITS THE LUNGS DURING ONE MINUTE OF BREATHING

15

WE NORMALLY BREATHE BETWEEN 15 AND 16 TIMES A MINUTE.

Larynx

The resonance box that houses the vocal cords; it consists of various components of cartilaginous tissue. One of these components can be identified externally: it is the Adam's apple, or thyroid cartilage, located in the middle of the throat. The larynx is important for respiration because it links the pharynx with the trachea and ensures the free passage of air entering and leaving the lungs. It closes the epiglottis like a door when the organism is ingesting food in order to prevent food from entering the airway.



WHAT ENTERS AND WHAT EXITS

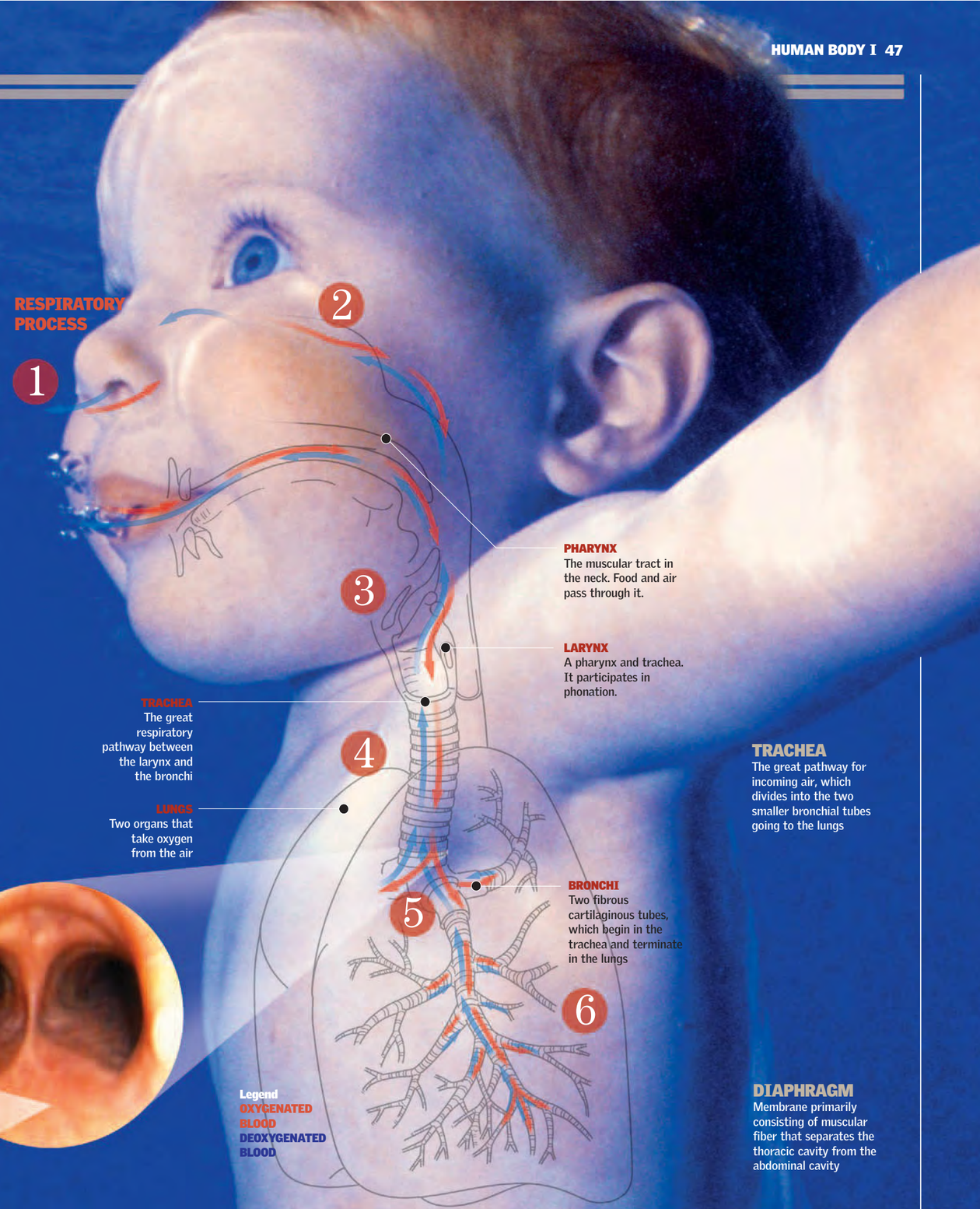
Component	Percentage in Inhaled Air	Percentage of Exhaled Air
Nitrogen	78.6	78.6
Oxygen	20.8	15.6
Carbon Dioxide	0.04	4
Water Vapor	0.56	1.8
Total	**100**	**100**

Route

1. The air enters the nasal cavity, where it is heated, cleaned, and humidified (it also enters through the mouth).
2. The air passes through the pharynx, where the tonsils intercept and destroy harmful organisms.
3. The air passes through the larynx, whose upper part, the epiglottis, a cartilaginous section, prevents food from passing into the larynx when swallowing. From the larynx the air goes into the esophagus.
4. The air passes through the trachea, a tube lined with cilia and consisting of rings of cartilage that prevent its deformation. The trachea transports air to and from the lungs.
5. In the thoracic region the trachea branches into two bronchi, which are subdivided into smaller branches, the bronchioles, which in turn carry the air to the pulmonary alveoli, elastic structures shaped like sacs where gas exchange occurs.
6. From the alveoli the oxygen passes into the blood and then from the blood to the tissues of the body. The carbon dioxide exits the bloodstream and travels toward the alveoli to be subsequently exhaled. Exhaled air contains more carbon dioxide and less oxygen than inhaled air.

HAIRS

The interior of the trachea is covered with hairs (cilia), which, like the hairs in the nose, capture dust or impurities carried by the air.



TRACHEA

The great pathway for incoming air, which divides into the two smaller bronchial tubes going to the lungs

DIAPHRAGM

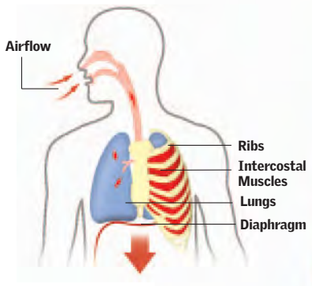
Membrane primarily consisting of muscular fiber that separates the thoracic cavity from the abdominal cavity

Lungs

Their principal function is to exchange gases between the blood and the atmosphere. Inside the lungs, oxygen is taken from the air, and carbon dioxide is returned to the air. There are two lungs. The left lung has two lobes and one lingula, and it weighs approximately 30 ounces (800 g); the right lung has three lobes and weighs 35 ounces (1,000 g). Both lungs process the same amount of air. In men each lung has a capacity of 3 quarts (3.2 l), and in women, 2 quarts (2.1 l). The lungs fill most of the space in the thoracic cage surrounding the heart. Their major motions are inhalation (taking in air) and exhalation (expulsion). The pleural membranes, intercostal muscles, and diaphragm make this mobility possible.

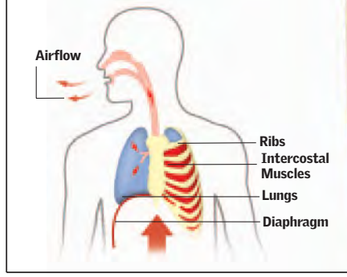
Inhalation

The air enters. The diaphragm contracts and flattens. The external intercostal muscles contract, lifting the ribs upward. A space is created within the thorax into which the lungs expand. The air pressure in the lungs is less than that outside the body, and therefore air is inhaled.



Exhalation

The diaphragm relaxes and becomes dome-shaped. The external intercostal muscles relax. The ribs move downward and inward. The space within the thorax decreases, and the lungs are compressed. The air pressure within the lungs is greater than that outside of the body, and therefore the air is exhaled.



A Marvelous Pump

The respiratory system accomplishes its functions by combining a series of involuntary and automatic movements. The lungs, opening and closing like bellows, make inhalation possible by increasing their capacity to take in air, which is then exhaled when the bellows close. Inside the lungs the first stage of processing the gases that came in through the nose and the trachea is accomplished. Once the exchange of oxygen to be absorbed and carbon dioxide to be expelled occurs, the next stages can be accomplished: transport of the gases and delivery of oxygen to the cells and tissues.

30,000

THE NUMBER OF BRONCHIOLES, OR TINY BRANCHINGS OF THE BRONCHI, IN EACH LUNG

350 million

THE NUMBER OF ALVEOLI IN EACH LUNG (700 MILLION FOR BOTH TOGETHER)

PLEURAL MEMBRANES are primarily muscular and allow the lungs to move within the rib cage.

TRACHEA
The trachea is reinforced with C-shaped pieces of cartilage.

PULMONARY ARTERY
The only blue artery. The oxygen-poor blood goes from the right side of the heart to the lungs to pick up oxygen.

AORTAL ARTERY
Recharged with oxygen from the lungs, the blood returns to the heart and then circulates through the entire body.

BRONCHIAL TREE
The complex of tubes that bring air to and from the lungs. They diminish in size from the trachea and subdivide into bronchioles and alveoli.

BRONCHI
One for each lung; the two great pathways into which the trachea is divided

Alveoli

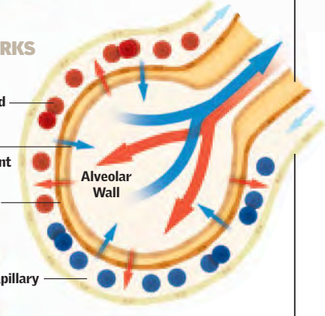
Hollow structures that terminate in the bronchioles. They store air, have the form of a globe or cluster of bubbles, and are active in gas exchange. The oxygen comes to the blood via the alveolar walls and then passes toward the capillary network. Carbon dioxide is transferred from the blood to the alveoli and is then exhaled. If the alveoli are damaged as the result of a pulmonary disorder, then there is less surface area available for the interchange of gases, and the person might feel shortness of breath.

Intercostal Muscles

ALVEOLI
If dust or microorganisms enter, the macrophage cells defend against them.defienden.

Entry and Exit of Air

HOW IT WORKS



1. The alveolar cavity fills with air. The red arrows indicate the direction the oxygen travels toward the red blood cells and then on toward the heart and the rest of the body.
2. The blue indicates the direction the carbon dioxide travels to the red blood cells and the plasma from the heart so that the alveolar can return it to the lungs.
3. The complete operation of exchange is hematosis. The carbon dioxide will be returned to the lungs by the venae cavae and exhaled.

BRONCHIOLES
are thinner than a human hair. They secrete mucus.

Digestive System

The digestive system is the protagonist of a phenomenal operation that transforms food into fuel for the entire body. The process begins with ingestion through the mouth and esophagus and continues with digestion in the stomach, the small intestine, and the large intestine, from which the feces are evacuated by the rectum and anus. By then the task will have involved important chemical components, such as bile, produced by the liver, and other enzymes, produced by the pancreas, by which the food is converted into nutrients. Separating the useful from the useless requires the filtering of the kidneys, which discard the waste in urine.

The First Step: Ingestion

The digestive process begins with the mouth, the entry point to the large tract that changes in form and function and ends at the rectum and anus. The tongue and teeth are the first specialists in the task. The tongue is in charge of tasting and positioning the food, which is cut and ground by the teeth. This synchronized activity includes the maxillary bones, which are controlled by their corresponding muscles. The palate, in the upper part of the mouth, prevents food from passing into the nose. The natural route of the food is down the esophagus to the stomach.

Teeth

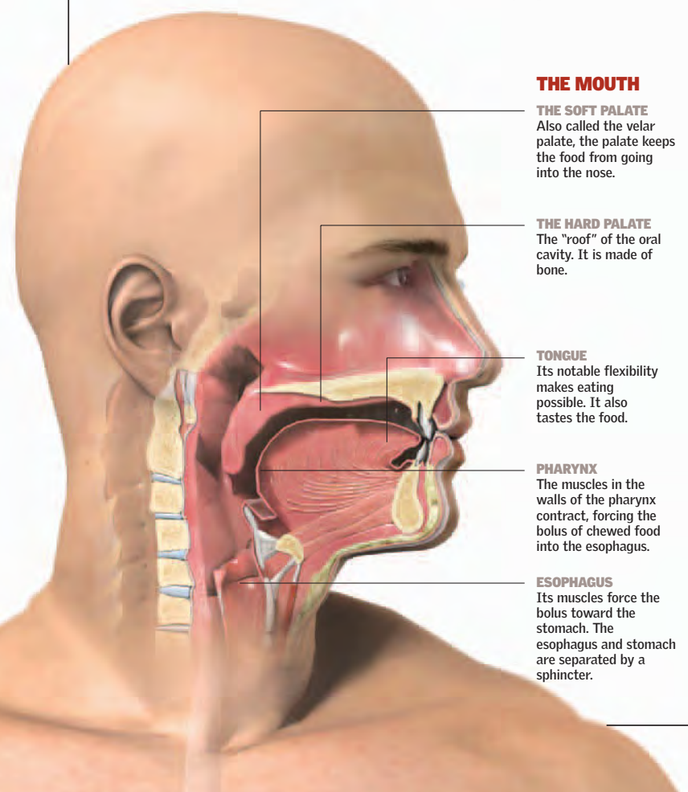
There are 32 teeth, and they are extremely hard, a condition necessary for chewing food. There are eight incisors, four canines, eight premolars, and 12 molars. Humans develop two sets of teeth, a provisional or temporary set (the baby teeth) and a permanent set (adult teeth). The first temporary teeth appear between six and 12 months of age. At 20 years of age the process of replacement that began at about age five or six is complete.

A SET OF TEETH

32

A PERSON NORMALLY HAS THIS NUMBER OF TEETH.

THE MOUTH



THE SOFT PALATE
Also called the velar palate, the palate keeps the food from going into the nose.

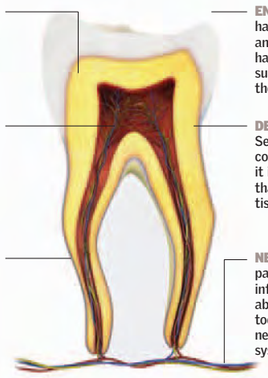
THE HARD PALATE
The "roof" of the oral cavity. It is made of bone.

TONGUE
Its notable flexibility makes eating possible. It also tastes the food.

PHARYNX
The muscles in the walls of the pharynx contract, forcing the bolus of chewed food into the esophagus.

ESOPHAGUS
Its muscles force the bolus toward the stomach. The esophagus and stomach are separated by a sphincter.

THE INSIDE OF A TOOTH



PULP
Soft tissue that is the core of the tooth

ROOT
Entirely buried in the maxillary bone

CEMENT
The thin layer that covers the roots and anchors them in the jawbone

ENAMEL
has no feeling and is the hardest substance in the body.

DENTIN
Sensitive to cold and heat, it is stronger than bone tissue.

NERVES
pass information about the tooth to the nervous system.

Enzymes and Hormones

The complex chemical processes that transform food are essentially accomplished by enzymes and hormones. Both types of substances are secreted by various glands of the digestive system, such as the salivary glands. Enzymes are substances that act as catalysts. Hormones are substances that regulate processes such as growth metabolism, reproduction, and organ function.

Digestion Chronology

The process that converts food into nutrients begins a few seconds after the food is raised to the mouth and chewing begins. The average digestion time is about 32 hours, though digestion can range from 20 to 44 hours.

1 00:00:00

The process begins when the food reaches the mouth. The entire organism is involved in the decision, but it is the digestive system that plays the main role. The first steps are taken by the teeth and the tongue, aided by the salivary glands, which provide saliva to moisten the alimentary bolus. The morsels are chewed so that they can pass through the esophagus.

2 00:00:10

About 10 seconds after chewing has begun, the food is transformed into a moist alimentary bolus that makes its way through the pharynx to the esophagus and then to the stomach, where other changes will take place.

3 03:00:00

Three hours after its arrival, the food leaves the stomach, which has accomplished its function. The first phase of digestion is over. The bolus now has a liquid and creamy consistency.

4 06:00:00

Three hours later, the food that has been digested in the stomach arrives at the midpoint of the small intestine. At this point it is ready to be absorbed.

5 08:00:00

Two hours later, the non-digested, watery residue arrives at the junction of the small and large intestines. The useless material rejected by the body's chemical selectors continues its course, and it is now prepared to be expelled from the organism in the form of feces.

20:00:00

The alimentary residue remains in the large intestine between 12 and 28 hours. In this part of the process the residue is converted into semisolid feces.

6 24:00

Between 20 and 44 hours after having entered the mouth as food, the residue that was converted into semisolid feces in the previous stage arrives at the rectum. The waste will be evacuated through the anus as excrement.

Tract

The muscular movement called peristalsis pushes the food along. That is why it is possible to eat upside down or during weightlessness, as astronauts do.

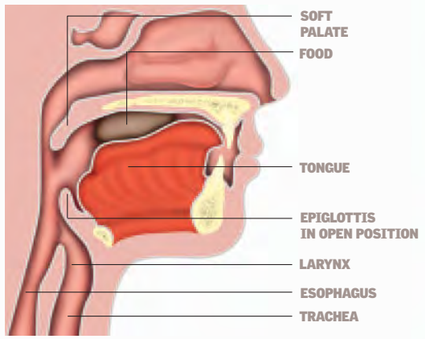
10 inches (25 cm)
IS THE LENGTH OF THE ESOPHAGUS.

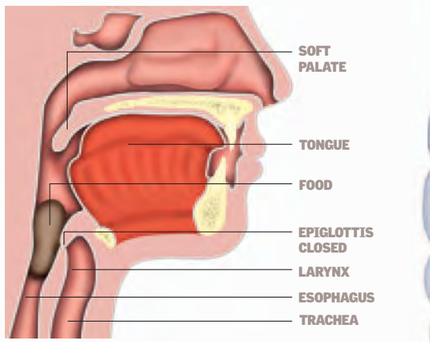
Stomach

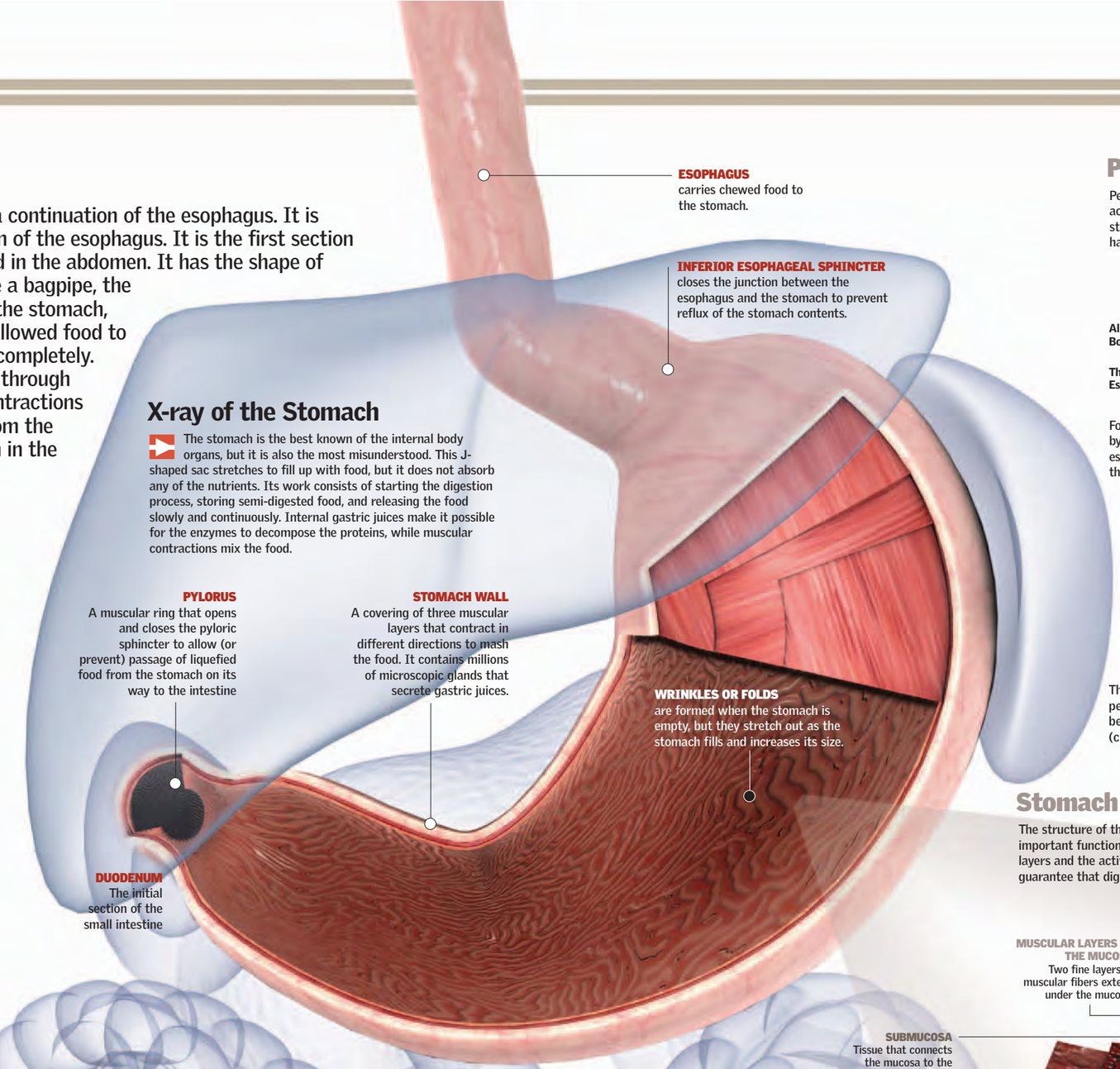
The part of the digestive tract that is a continuation of the esophagus. It is sometimes thought of as an expansion of the esophagus. It is the first section of the digestive system that is located in the abdomen. It has the shape of an empty bag that is curved somewhat like a bagpipe, the handle of an umbrella, or the letter "J." In the stomach, gastric juices and enzymes subject the swallowed food to intense chemical reactions while mixing it completely. The stomach connects with the duodenum through the pylorus. Peristalsis, or the muscular contractions of the alimentary canal, moves the food from the stomach to the duodenum, the next station in the progress of the alimentary bolus.

How We Swallow

Although swallowing is a simple act, it does require the coordination of multiple parts. The soft palate moves backward when the alimentary bolus passes through the esophagus. The epiglottis moves downward to close the trachea and prevent the food from entering the respiratory pathways. The alimentary bolus is advanced by the muscular motions of peristalsis.







X-ray of the Stomach

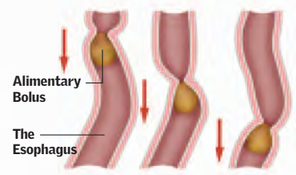
The stomach is the best known of the internal body organs, but it is also the most misunderstood. This J-shaped sac stretches to fill up with food, but it does not absorb any of the nutrients. Its work consists of starting the digestion process, storing semi-digested food, and releasing the food slowly and continuously. Internal gastric juices make it possible for the enzymes to decompose the proteins, while muscular contractions mix the food.

20 times

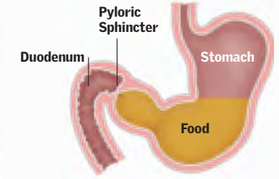
THE STOMACH INCREASES UP TO 20 TIMES ITS ORIGINAL SIZE AFTER A PERSON EATS.

Peristalsis: Muscles in Action

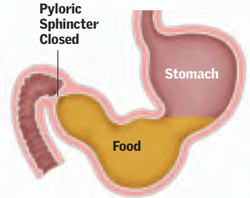
Peristalsis is the group of muscular actions that moves the food toward the stomach and, once the digestive stage has been completed, moves it on to the small intestine. The sphincters are stationary, ring-shaped muscular structures whose opening and closing regulates the passage of the bolus.



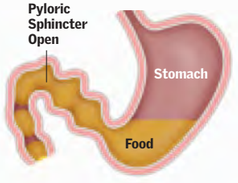
Food is sent toward the stomach, pumped by the muscular contractions of the esophageal walls. Gravity helps accomplish this downward journey.



Full stomach. Food enters. The pyloric sphincter remains closed. The gastric juices kill bacteria and are mixed with the food through muscular motions.



The stomach in full digestive action. The peristaltic muscles mix the food until it becomes a creamy, viscous liquid (chyme).



The stomach is being emptied. The pyloric sphincter relaxes, the muscles move the food, and small quantities of food exit toward the duodenum.

Stomach Wall

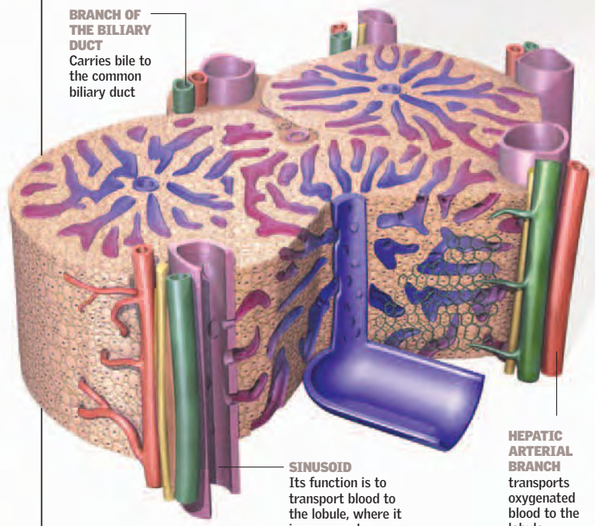
The structure of the wall accounts for the two important functions of the stomach: the muscular layers and the activity of the gastric glands guarantee that digestion will run its course.

Liver, Pancreas, Bile

The liver is the largest gland of the human body and the second largest organ (the skin is the largest). It has numerous functions, and a large part of the body's general equilibrium depends on it. The liver produces bile, a yellowish-green fluid that helps in the digestion of fats. The liver is the great regulator of the glucose level of the blood, which it stores in the form of glycogen. Glycogen can be released when the organism requires more sugar for activity. The liver regulates the metabolism of proteins. Proteins are the essential chemical compounds that make up the cells of animals and plants. The liver is also a large blood filter and a storage site for vitamins A, D, E, and K. The pancreas is a gland that assists in digestion, secreting pancreatic juice.

Lobules

Among its other functions, the liver processes nutrients to maintain an adequate level of glucose in the blood. This task requires hundreds of chemical processes that are carried out by the hepatocytes, or liver cells. These are arranged in columns, forming structures called lobules. They produce bile and a sterol (a solid steroid alcohol) called cholesterol. They also eliminate toxins that might be present in food.



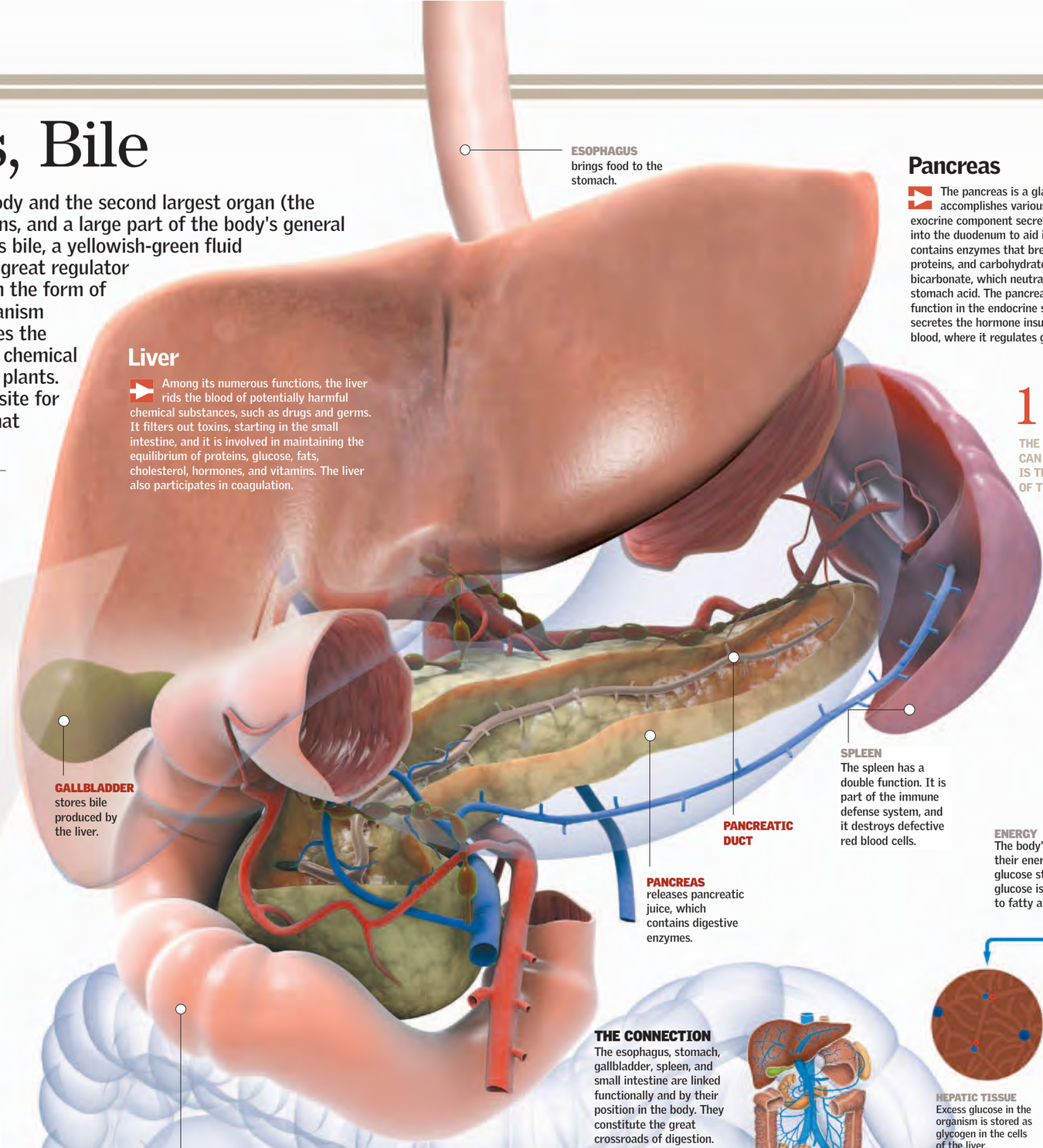
BRANCH OF THE BILIARY DUCT
Carries bile to the common biliary duct

SINUSOID
Its function is to transport blood to the lobule, where it is processed.

HEPATIC ARTERIAL BRANCH
transports oxygenated blood to the lobule.

Vesicle and Bile

The biliary system stores bile that is produced by the hepatocytes in a specialized pouch called the gallbladder. The path the bile takes from the liver to the gallbladder leads through little canals, biliary ducts, and hepatic ducts, whose diameter increases as the bile moves along. When the body ingests fat, the bile is sent from the gallbladder to the small intestine to accomplish its main function: emulsifying fats to help promote their later absorption.



ESOPHAGUS
brings food to the stomach.

GALLBLADDER
stores bile produced by the liver.

DUODENUM
The initial part of the small intestine

PANCREAS
releases pancreatic juice, which contains digestive enzymes.

PANCREATIC DUCT

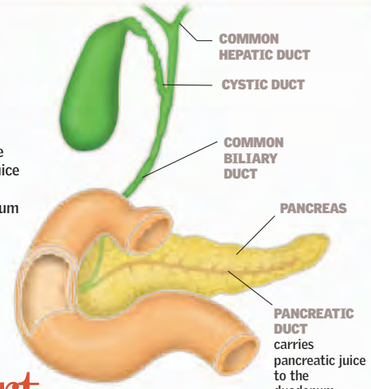
SPLEEN
The spleen has a double function. It is part of the immune defense system, and it destroys defective red blood cells.

Liver

Among its numerous functions, the liver rids the blood of potentially harmful chemical substances, such as drugs and germs. It filters out toxins, starting in the small intestine, and it is involved in maintaining the equilibrium of proteins, glucose, fats, cholesterol, hormones, and vitamins. The liver also participates in coagulation.

Pancreas

The pancreas is a gland that accomplishes various functions. Its exocrine component secretes pancreatic juice into the duodenum to aid in digestion. This juice contains enzymes that break down fats, proteins, and carbohydrates. It contains sodium bicarbonate, which neutralizes the strong stomach acid. The pancreas also performs a function in the endocrine system: it secretes the hormone insulin into the blood, where it regulates glucose levels.



COMMON HEPATIC DUCT

CYSTIC DUCT

COMMON BILIARY DUCT

PANCREAS

PANCREATIC DUCT
carries pancreatic juice to the duodenum.

1 quart (0.9 l)

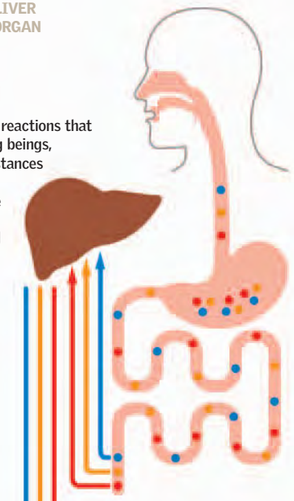
THE AMOUNT OF BILE THE LIVER CAN PRODUCE IN A DAY. THE LIVER IS THE HEAVIEST INTERNAL ORGAN OF THE BODY.

THE CONNECTION

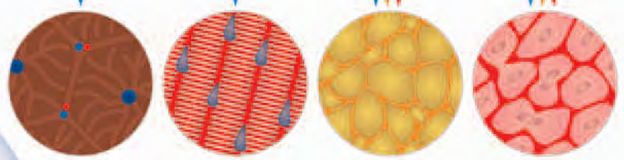
The esophagus, stomach, gallbladder, spleen, and small intestine are linked functionally and by their position in the body. They constitute the great crossroads of digestion.

Metabolism

The complex of chemical reactions that occur in the cells of living beings, transforming simple substances into complex substances and vice versa. When the nutrients are absorbed into the bloodstream and passed to the liver, the liver breaks down proteins into amino acids, fats into fatty acids and glycerol, and carbohydrates into smaller components. A normal diet includes carbohydrates, proteins, fats, vitamins, and minerals.



ENERGY
The body's cells basically obtain their energy from the breakdown of glucose stored in the liver. When no glucose is available, the body turns to fatty acids for energy.



HEPATIC TISSUE
Excess glucose in the organism is stored as glycogen in the cells of the liver.

MUSCULAR FIBER
Muscle cells in the liver together with the hepatic cells store glycogen.

ADIPOSE CELLS
are cells in which the organism stores excess fatty acids in the form of fat.

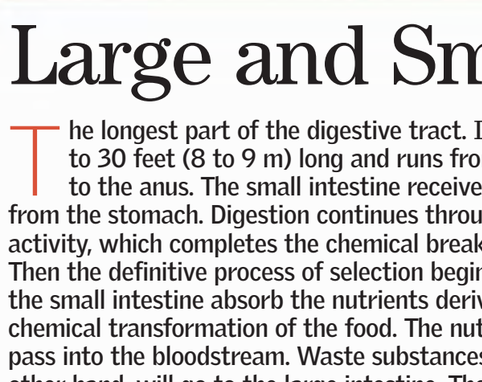
CELLULAR GROWTH AND REPAIR
Amino acids are converted into proteins by a process called anabolism. Proteins are fundamental for mitosis, cellular regeneration, and enzyme production.

Large and Small Intestine

The longest part of the digestive tract. It is about 26 to 30 feet (8 to 9 m) long and runs from the stomach to the anus. The small intestine receives the food from the stomach. Digestion continues through enzyme activity, which completes the chemical breakdown of the food. Then the definitive process of selection begins: the walls of the small intestine absorb the nutrients derived from the chemical transformation of the food. The nutrients then pass into the bloodstream. Waste substances, on the other hand, will go to the large intestine. There the final stage of the digestive process will occur: the formation of the feces to be excreted.

The Union of Both

The small and large intestines join at the section called the ileum (which is the final section of the small intestine; the duodenum and jejunum come before the ileum). The iliac valve acts as a door between the small intestine and large intestine, or colon. The ileum terminates in the caecum (of the large intestine). The ileum measures approximately 13 feet (4 m) in length. Its primary function is the absorption of vitamin B12 and biliary salts. The primary function of the large intestine is the absorption of water and electrolytes that arrive from the ileum.



WATER THAT ENTERS THE ALIMENTARY CANAL

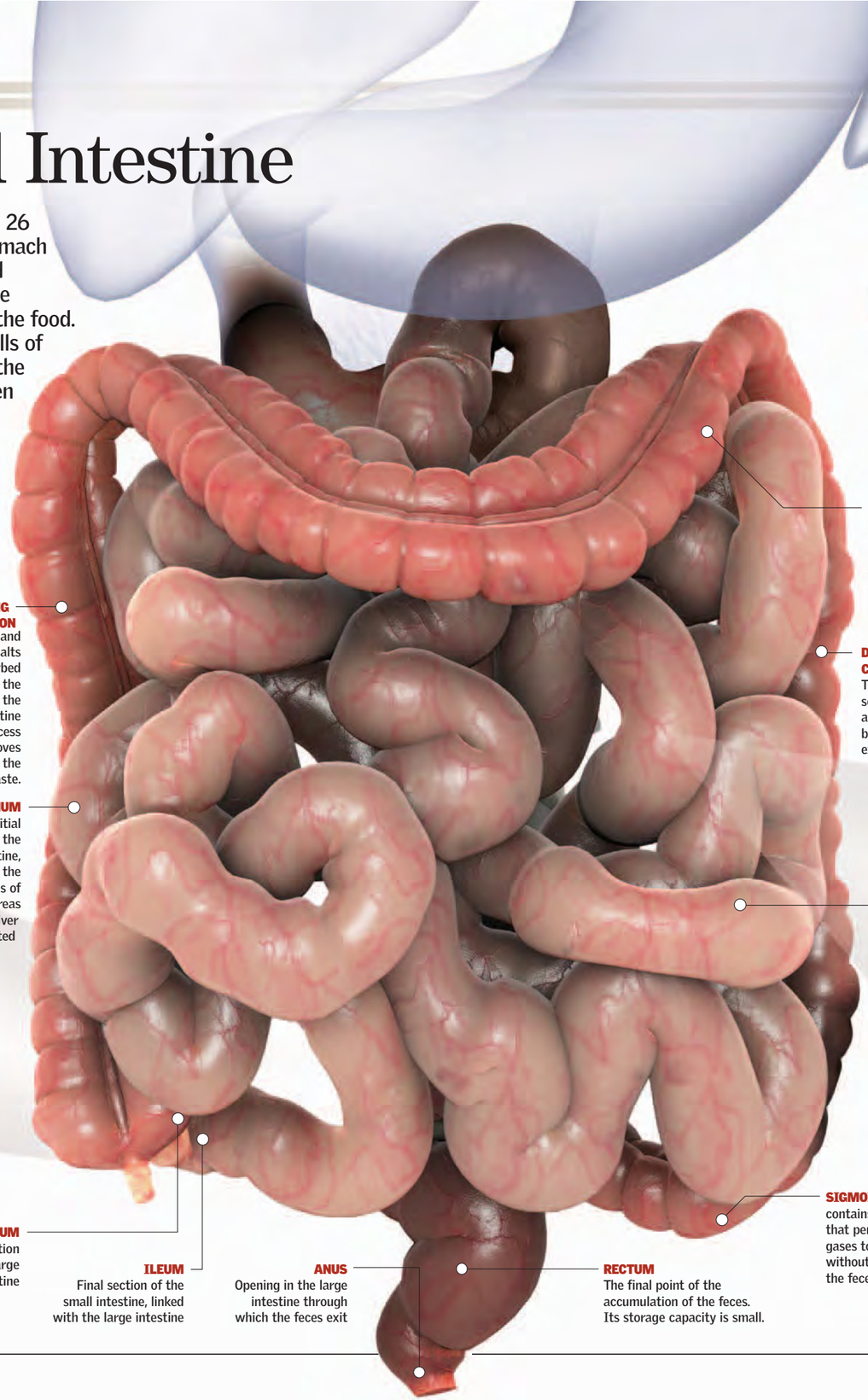
In fluid ounces

Saliva	34	(1 l)
Water from Drinking	77	(2.3 l)
Bile	34	(1 l)
Pancreatic Juice	68	(2 l)
Gastric Juice	68	(2 l)
Intestinal Juice	34	(1 l)
Total	**313**	**(9.3 l)**

WATER REABSORBED BY THE ALIMENTARY CANAL

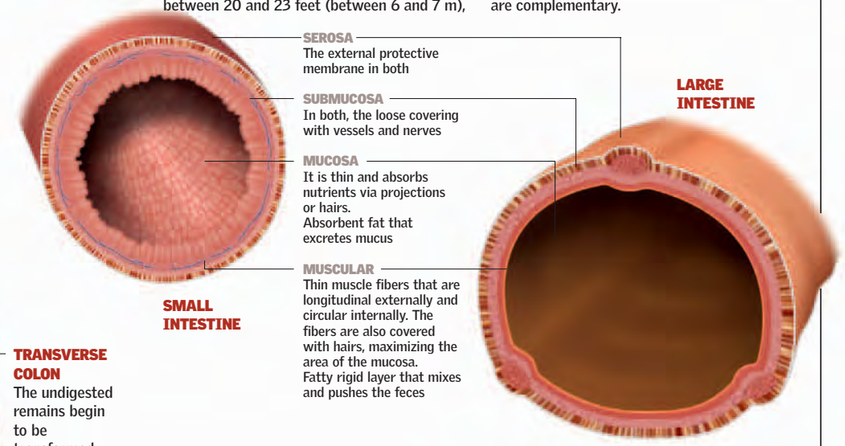
In fluid ounces

Small Intestine	280	(8.3 l)
Large Intestine	30	(0.9 l)
Subtotal	310	(9.2 l)
Water Lost in the Feces	3	(0.1 l)
Total	**313**	**(9.3 l)**



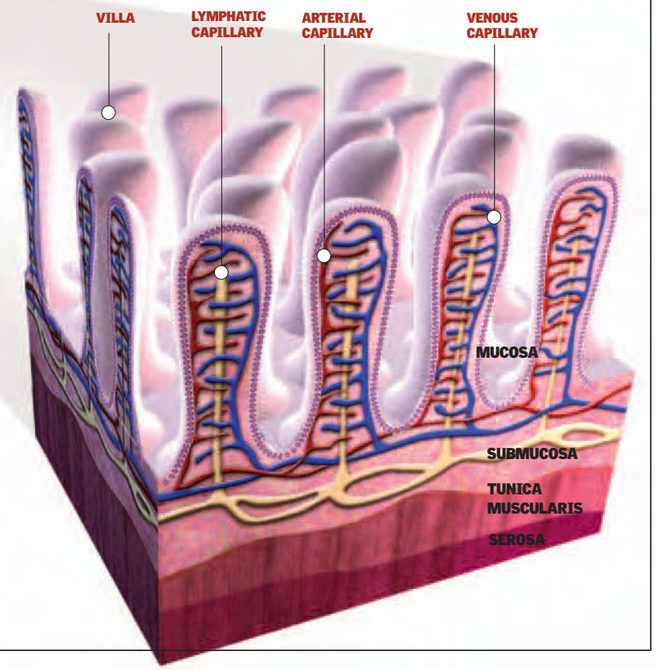
Differences and Similarities

The small intestine is longer than the large intestine. The length of the small intestine is between 20 and 23 feet (between 6 and 7 m), and the large intestine averages 5 feet (1.5 m). Their respective composition and functions are complementary.



Villa

The internal wall of the small intestine is covered with millions of hairlike structures called villi. Each one has a lymphatic vessel and a network of vessels that deliver nutrients to it. Each villus is covered by a cellular layer that absorbs nutrients. Together with epithelial cells, the villi function to increase the surface area of the intestine and optimize the absorption of nutrients.



Urinary System

Its basic organs are the kidneys (2), the ureters (2), the bladder, and the urethra. Its function is to regulate homeostasis, maintaining the equilibrium between the water and the chemicals in the body. The first phase of this objective is accomplished when the kidneys produce and secrete urine, a liquid that is eliminated from the body. Urine is essentially harmless, only containing about 2 percent urea, and is sterile: it is composed primarily of water and salts, and it normally does not contain bacteria, viruses, or fungi. The ureters are channels that carry the urine through the body. The bladder is a sac that stores the urine until it is passed to the urethra, a duct through which it will be expelled from the body.

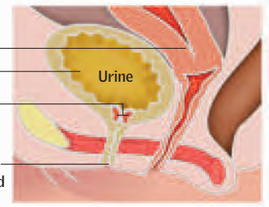
The Urinary Tract

The glomerulus is a grouping of vessels located in the cortex of the kidneys. Most of the filtering that takes place in the nephron is performed in the glomerulus. Wide arterioles carry blood to the glomerulus. Other, thinner arterioles exit from the glomerulus, carrying away blood. So much pressure is generated inside the kidney that the fluid exits from the blood via the porous capillary walls.

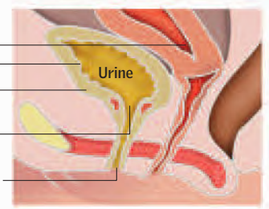
The Bladder in Action

The bladder is continually filled with urine and then emptied periodically. When full, the bladder stretches to increase its capacity. When the muscle of the internal sphincter is relaxed, the muscles of the wall contract, and the urine exits through the urethra. In adults this occurs voluntarily in response to an order issued by the nervous system. In infants, on the other hand, this evacuation occurs spontaneously, as soon as the bladder is filled.

FILLING



EMPTYING



Legend

1. BLOOD FILTERING
The blood enters the kidney via the renal artery.

2. TRANSFER
The artery carries the blood into the kidney, where it is filtered by the kidney's functional units, the nephrons.

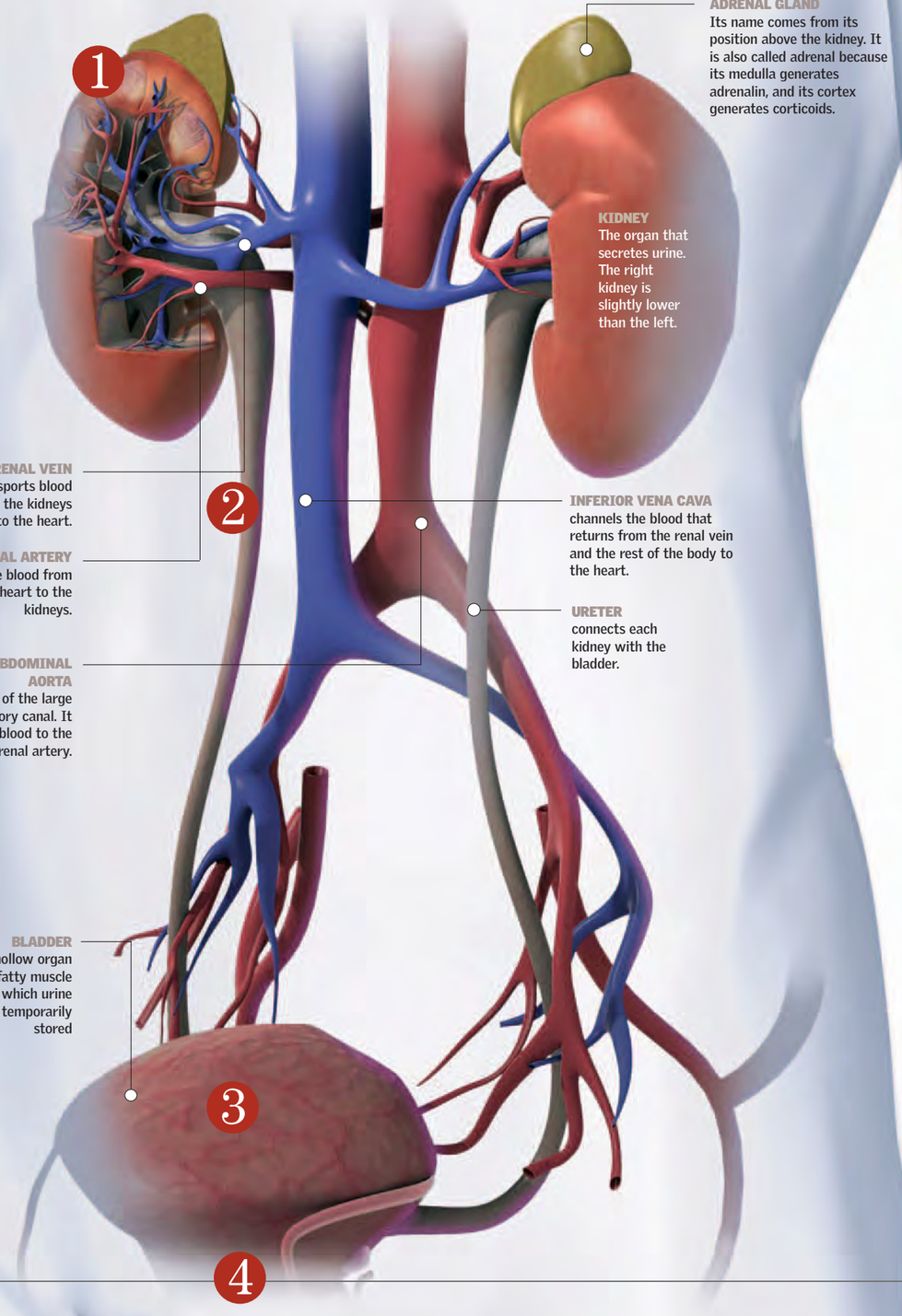
3. STORAGE
A certain amount of urine is obtained from the filtrate in the nephrons, and that urine is sent to the renal pelvis.

4. ELIMINATION
The urine passes from the renal pelvis to the ureter and then to the bladder, where it accumulates until it is eliminated through the tube-shaped urethra.

15 minutes
IT TAKES 15 MINUTES FOR LIQUIDS TO CIRCULATE THROUGH THE NEPHRONS.

COMPONENTS OF URINE

95%	**Water**
2%	**Urea,** a toxic substance
2%	**Chloride salts,** sulfates, phosphates of potassium and magnesium
1%	**Uric acid**



ADRENAL GLAND
Its name comes from its position above the kidney. It is also called adrenal because its medulla generates adrenalin, and its cortex generates corticoids.

KIDNEY
The organ that secretes urine. The right kidney is slightly lower than the left.

RENAL VEIN
transports blood filtered by the kidneys to the heart.

RENAL ARTERY
brings the blood from the heart to the kidneys.

ABDOMINAL AORTA
A section of the large circulatory canal. It provides blood to the renal artery.

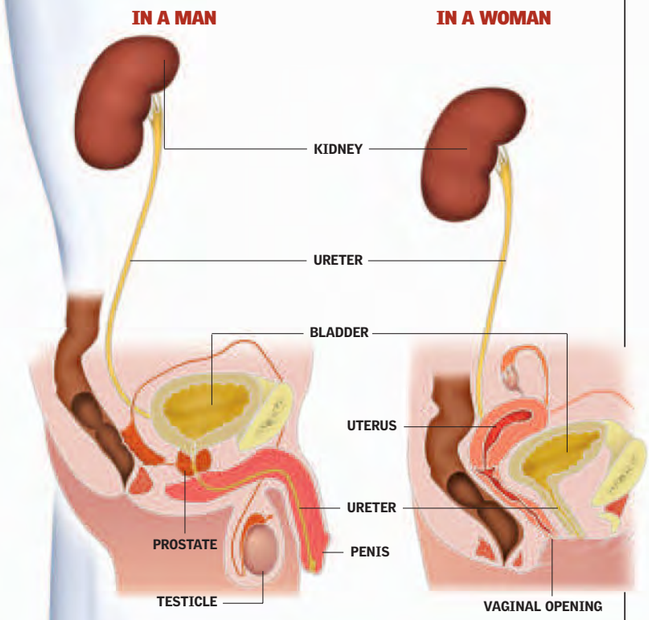
INFERIOR VENA CAVA
channels the blood that returns from the renal vein and the rest of the body to the heart.

URETER
connects each kidney with the bladder.

BLADDER
A hollow organ with a fatty muscle wall in which urine is temporarily stored

Differences by Sex

The urinary system has a double relationship to the reproductive system. The two systems are linked by their close physical proximity, but they are also linked functionally. For example, the ureter is a vehicle for secretions produced by the glands of both systems. The urinary systems in men and women are different. A man's bladder is larger, and the male ureter is also larger than a woman's, because in a man the ureter extends to the end of the penis, for a total length of about 6 inches (20 cm); in a woman, on the other hand, the bladder is located at the front of the uterus, and the length of the ureter is approximately 1.5 inches (4 cm).



Fluid Exchange

The volume of urine that a person expels every day is related to the person's consumption of liquids. Three quarts (2.5 l) a day would be excessive, but a significant decrease in the production of urine can indicate a problem. The table details the relationship between the consumption of liquid and its expulsion by the different glands of the human body.

CONSUMPTION OF WATER

Drinking	**60%**
50 fluid ounces (1,500 ml)	
Food	**30%**
25 fluid ounces (750 ml)	
Metabolic water	**10%**
16 fluid ounces (250 ml)	
3 quarts (2,500 ml) TOTAL	

EXPULSIÓN DE AGUA

Urine	**60%**
50 fluid ounces (1,500 ml)	
Losses through the lungs and the skin	**28%**
25 fluid ounces (700 ml)	
Sweat	**8%**
16 fluid ounces (200 ml)	
Feces	**4%**
3 fluid ounces (100 ml)	
3 quarts (2,500 ml) TOTAL	

Kidneys

Located on either side of the spinal column, the kidneys are the fundamental organs of the urinary system. They regulate the amount of water and minerals in the blood by producing urine that carries away the waste the kidneys discard. They keep the composition of the bodily fluids constant, regulate the pressure of the arteries, and produce important substances such as the precursor of vitamin D and erythropoietin. Every day they process 500 gallons (1,750 l) of blood and produce 2 quarts (1.5 l) of urine. The kidneys measure approximately 5 inches (12 cm) long and 3 inches (6 cm) wide. Their weight is only 1 percent of the total body weight, but they consume 25 percent of its energy. If one kidney ceases to function, the body is able to survive with the activity of the other.

The Renal Circuit

Urine is produced in the nephrons in each kidney; there are thought to be a million nephrons in each kidney. From the nephrons the urine flows into the proximal convoluted tubule, where all the nutrients, such as glucose, amino acids, and most of the water and salts, are reabsorbed into the blood. After passing through the nephron the urine is filtered, and it arrives at the common collecting duct where only the residues and excess water are retained.

1. ENTRY OF BLOOD
The blood enters the kidney via the renal artery.

2. FILTRATION
The blood is filtered in the nephrons, the functional units of the kidneys.

3. URINE IS OBTAINED
A certain amount of urine is obtained from the filtrate in the nephrons, and it is sent to the renal pelvis. The filtered blood, free from waste, is sent to the renal vein and reenters the bloodstream.

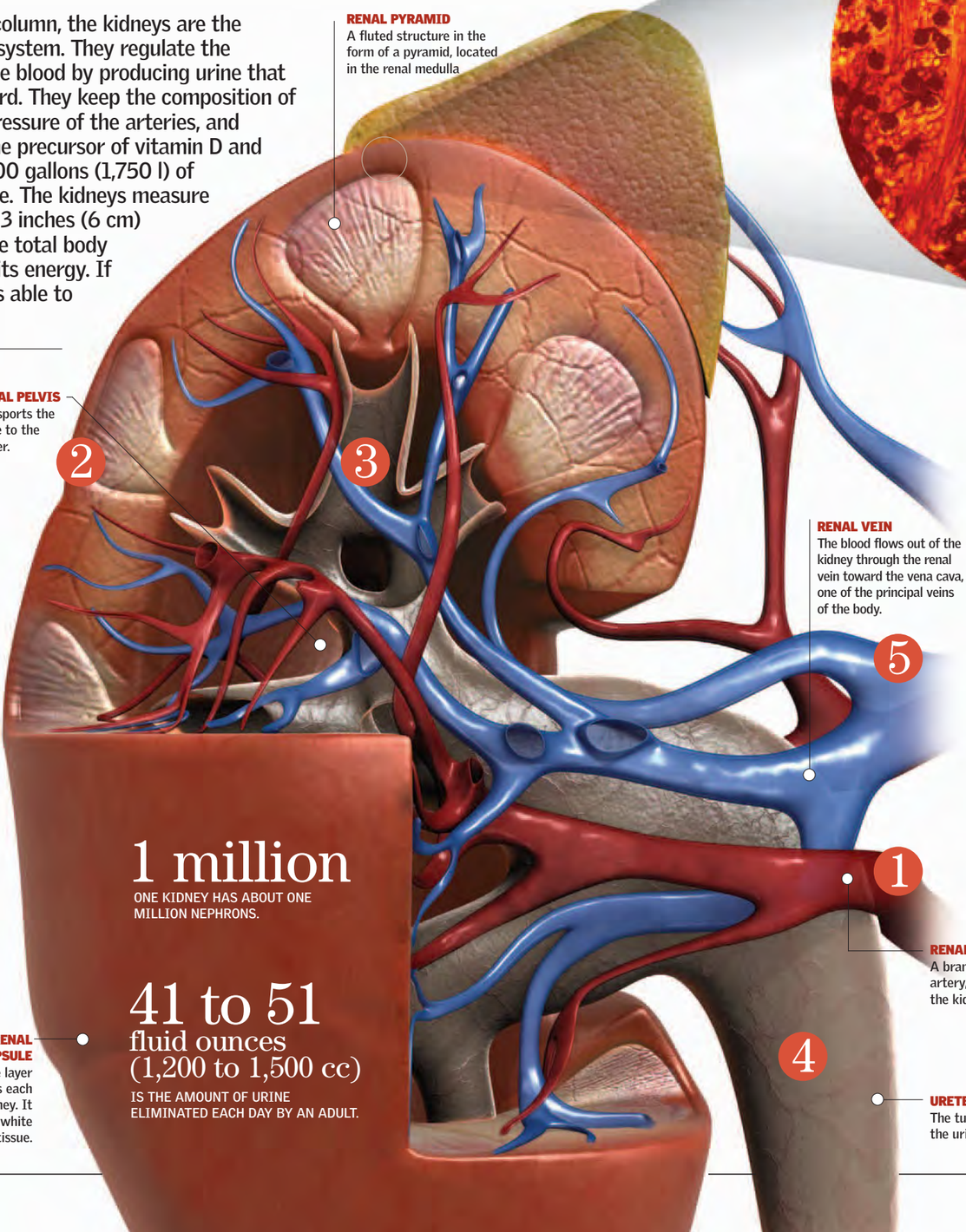
4. URINE
The urine passes through the renal pelvis to the ureter and from there to the bladder, where it accumulates until it is eliminated through the tube-shaped urethra.

5. CLEAN BLOOD
The clean blood exits the kidney via the renal vein, which is connected to the vena cava. The blood then returns to the heart.

45 minutes

THE FRENCH PHYSIOLOGIST CLAUDE BERNARD (1813-78) WAS THE FIRST TO NOTE THE IMPORTANCE OF THE KIDNEYS.

At that time it was not known that the kidneys filter all the water content of the blood in the body every 45 minutes and that, even so, it is possible to survive with only one kidney (or none, in the case of dialysis).



RENAL PYRAMID
A fluted structure in the form of a pyramid, located in the renal medulla

RENAL PELVIS
transports the urine to the ureter.

RENAL VEIN
The blood flows out of the kidney through the renal vein toward the vena cava, one of the principal veins of the body.

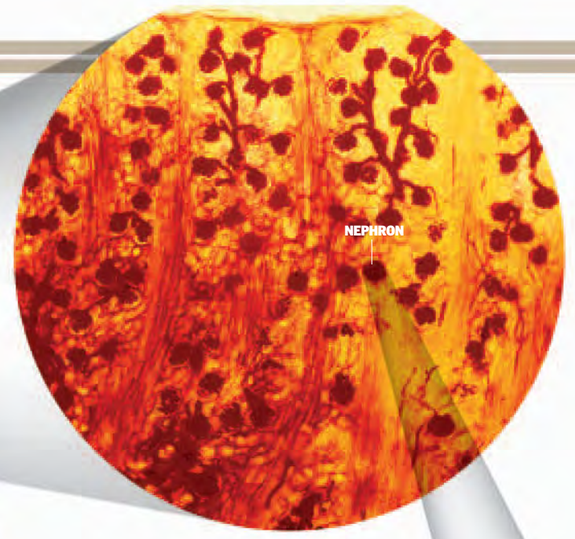
RENAL ARTERY
A branch of the aortic artery, which provides the kidney with blood

URETER
The tube that transports the urine to the bladder

RENAL CAPSULE
Protective layer that covers each kidney. It consists of white fibrous tissue.

1 million
ONE KIDNEY HAS ABOUT ONE MILLION NEPHRONS.

41 to 51 fluid ounces (1,200 to 1,500 cc)
IS THE AMOUNT OF URINE ELIMINATED EACH DAY BY AN ADULT.

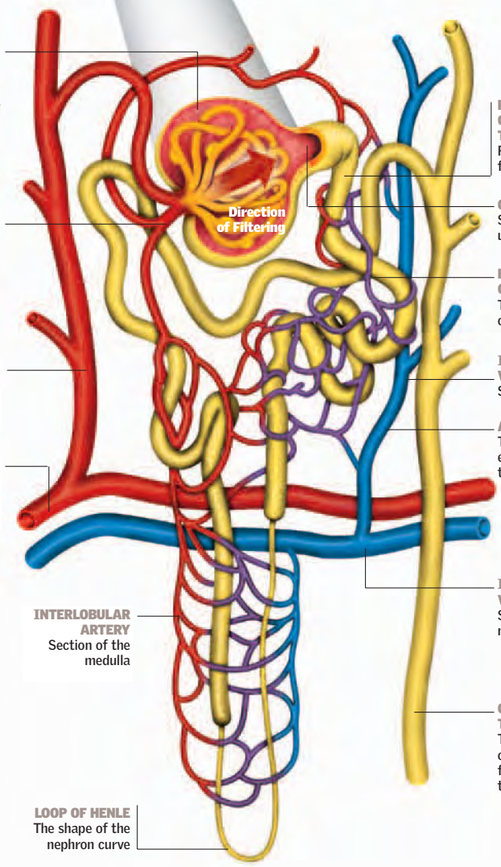


Glomerulus

A grouping of vessels and capillaries in the kidney's cortex, or sheath. Most of the filtering done by the nephrons takes place there. The wide, afferent arterioles bring blood to the glomerulus. Other, narrower, efferent arterioles lead out of the glomerulus, transporting blood. Inside the glomerulus so much pressure is generated that substances in the blood pass out through the porous capillary walls.

Nephrons

The functional units of the kidney that filter the blood and produce urine. The basic structure of the nephron consists of two parts: (1) the renal or Malpighian corpuscle, where filtration occurs, including the glomerulus and Bowman's capsule that envelops it; and (2) the renal tubule, a tube that collects the filtered liquid (urine) that is to be eliminated from the body.



BOWMAN'S CAPSULE
First stage of the filtrate. It surrounds a fluid consisting of water, potassium, bicarbonate, sodium, glucose, amino acids, urea, and uric acid.

EFFERENT ARTERIOLE
Glomerulus salt

ARCUATE ARTERY
feeds the afferent arterioles leading to the glomerulus.

INTERLOBULAR ARTERY
Section of the cortex

INTERLOBULAR ARTERY
Section of the medulla

LOOP OF HENLE
The shape of the nephron curve

PROXIMAL CONVOLUTED TUBULE
First section of the filtrate's exit route

GLOMERULUS
Second stage, or ultrafiltrate

PERITUBULAR CAPILLARIES
The thinnest conduits

INTERLOBULAR VEIN
Section in the cortex

ARCUATE VEIN
Takes blood from the efferent arterioles of the glomerulus

INTERLOBULAR VEIN
Section in the medulla

COLLECTING TUBULE
Transports and concentrates the filtered liquid from the nephrons.

Endocrine System

Consists of the glands inside the body that secrete approximately 50 specific substances called hormones into the blood. The hormones activate or stimulate various organs and control reproduction, development, and metabolism. These chemicals control many of the body's processes and even meddle in our love lives.

The Hormonal Message

The endocrine system is made up of the so-called endocrine glands. This complex, controlled by the pituitary (hypophysis), or master, gland, includes the thyroid, parathyroid, pancreas, ovaries, testicles, adrenals, pineal, and hypothalamus. The role of these glands is to secrete the many hormones needed for body functions. The word "hormone" comes from the Greek *hormon*, which means to excite or incite. The term was suggested in 1905 by the British physiologist Ernest Starling, who in 1902 assisted in the isolation of the first hormone, secretin, which stimulates intestinal activity. Hormones control such functions as reproduction, metabolism (digestion and elimination of food), and the body's growth and development. However, by controlling an organism's energy and nutritional levels, they also affect its responses to the environment.

Pituitary Hormones

ACTH Adrenocorticotropin hormone. It goes to the adrenal gland.

TSH A hormone that stimulates the thyroid to produce the thyroid hormones, which influence metabolism, energy, and the nervous system.

GH Growth hormone

FSH Follicle-stimulating hormone

LH Luteinizing hormone; testosterone and estrogen

MSH Hormone that stimulates the melanocyte of the skin.

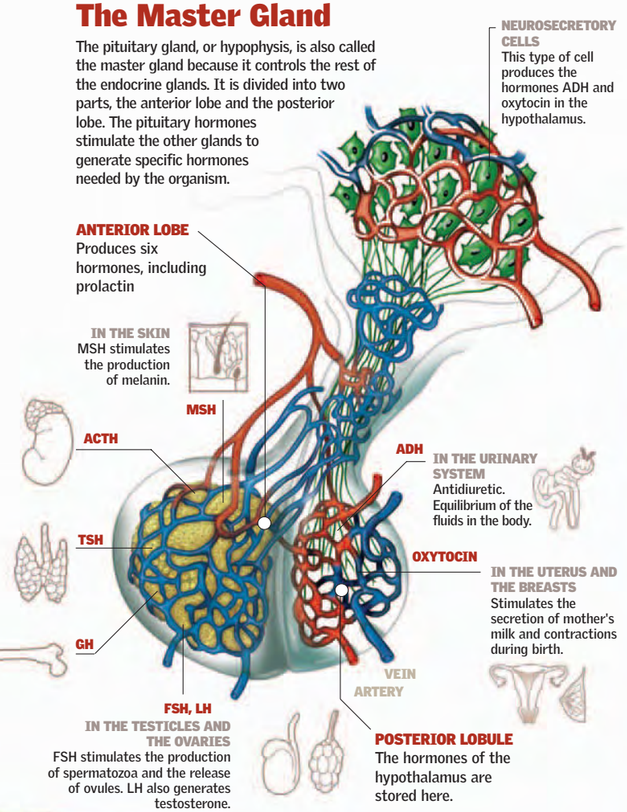
ADH Antidiuretic hormone

PRL Prolactin; stimulates milk production by the mother.

OXYTOCIN Stimulates the release of milk by the mother, as well as the contractions needed during labor.

The Master Gland

The pituitary gland, or hypophysis, is also called the master gland because it controls the rest of the endocrine glands. It is divided into two parts, the anterior lobe and the posterior lobe. The pituitary hormones stimulate the other glands to generate specific hormones needed by the organism.



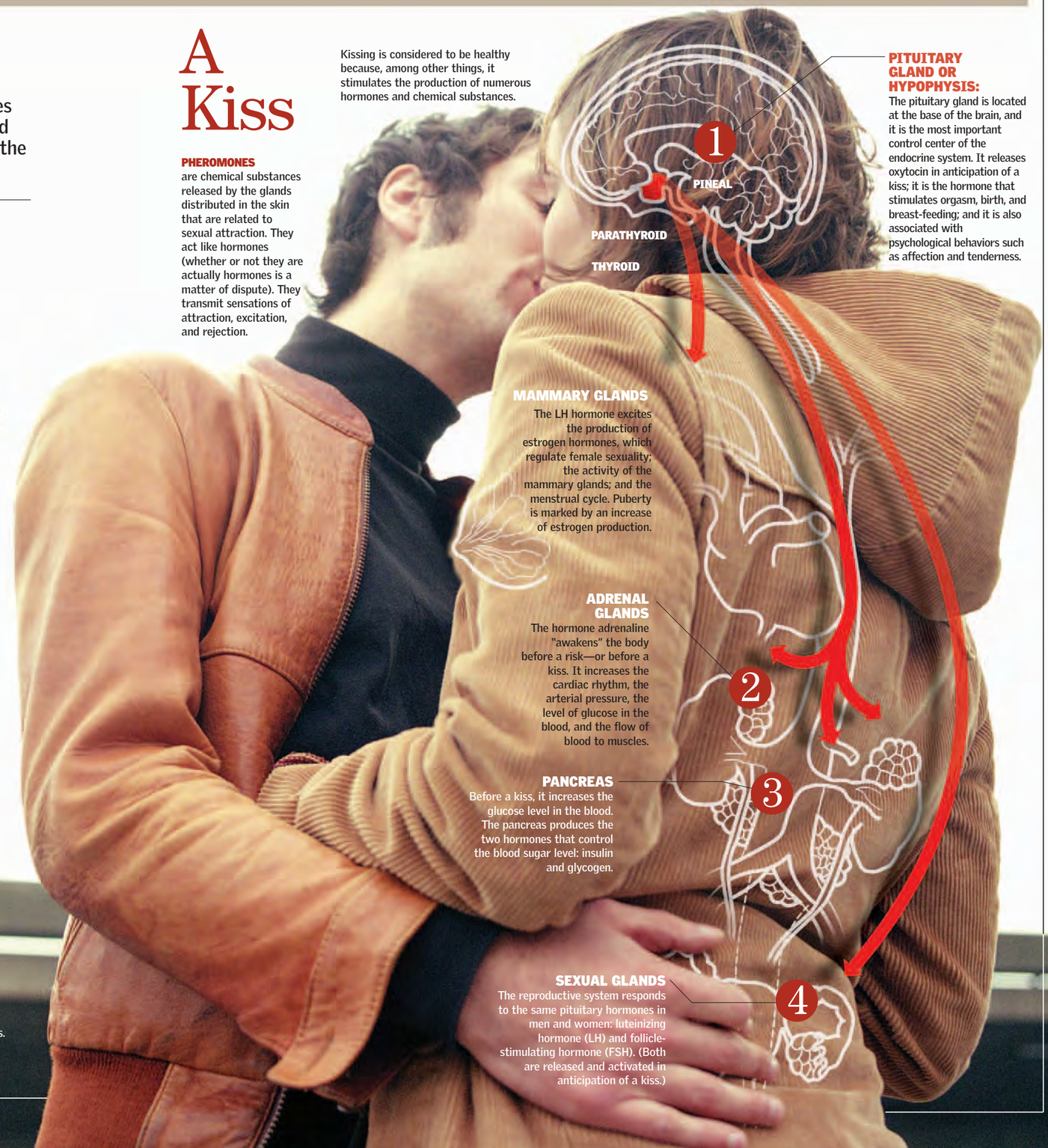
The Confidence Hormone

Oxytocin, the hormone that influences basic functions, such as being in love, orgasm, birth, and breast-feeding, is associated with affection and tenderness. It is a hormone that stimulates the formation of bonds of affection.

A Kiss

Kissing is considered to be healthy because, among other things, it stimulates the production of numerous hormones and chemical substances.

PHEROMONES are chemical substances released by the glands distributed in the skin that are related to sexual attraction. They act like hormones (whether or not they are actually hormones is a matter of dispute). They transmit sensations of attraction, excitation, and rejection.



PITUITARY GLAND OR HYPOPHYSIS: The pituitary gland is located at the base of the brain, and it is the most important control center of the endocrine system. It releases oxytocin in anticipation of a kiss; it is the hormone that stimulates orgasm, birth, and breast-feeding; and it is also associated with psychological behaviors such as affection and tenderness.

MAMMARY GLANDS The LH hormone excites the production of estrogen hormones, which regulate female sexuality; the activity of the mammary glands; and the menstrual cycle. Puberty is marked by an increase of estrogen production.

ADRENAL GLANDS The hormone adrenaline "awakens" the body before a risk—or before a kiss. It increases the cardiac rhythm, the arterial pressure, the level of glucose in the blood, and the flow of blood to muscles.

PANCREAS Before a kiss, it increases the glucose level in the blood. The pancreas produces the two hormones that control the blood sugar level: insulin and glycogen.

SEXUAL GLANDS The reproductive system responds to the same pituitary hormones in men and women: luteinizing hormone (LH) and follicle-stimulating hormone (FSH). (Both are released and activated in anticipation of a kiss.)

Male Reproductive System

The male reproductive system is the complex of organs that leads to a man's production of one of two types of cells necessary for the creation of a new being. The principal organs are the two testicles, or male gonads, and the penis. The testicles serve as a factory for the production of millions of cells called spermatozoa, which are minute messengers of conception bearing the genetic information for the fertilization of the ovum. The penis is linked to the urinary apparatus, but for reproduction it is the organ that functions as a vehicle for semen, a liquid through which the spermatozoa can reach their destination. The word "semen" comes from Greek and means "seed."

Testicles and Spermatozoa

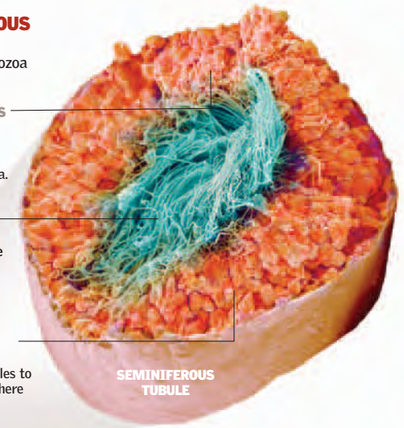
The seminiferous tubes in the testicles are covered with spermatogenic cells. By a process of successive cellular divisions called meiosis, the spermatogenic cells are transformed into spermatozoa, the term for the gametes, or male sexual cells, the bearers of half of the genetic information of a new individual. The spermatozoa fertilize the ovum, or female gamete, which contains the other half of the genetic information. The number of chromosomes is kept constant because the spermatozoa and the ovum are both haploid cells (cells that possess half of the genetic information of other cells). When the two haploid cells unite, the fertilized egg, or zygote, is a diploid cell (which contains a total of 46 chromosomes).

SEMINIFEROUS TUBULE
Where spermatozoa are produced

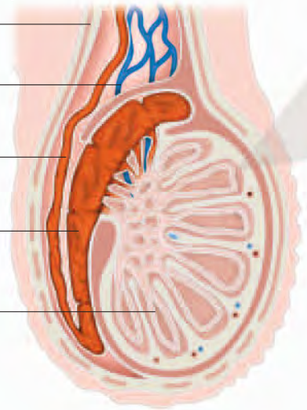
SPERMATOCYTES are formed by repeated reproduction of the spermatogonia.

MATURE SPERM
The division of the spermatocytes forms spermatozoa.

SPERMATOZOA move from the seminiferous tubules to the epididymis, where they are stored.



THE TESTICLES
The sexual organs that produce sperm



SPERMATIC CORD
Connects the testicles to the body

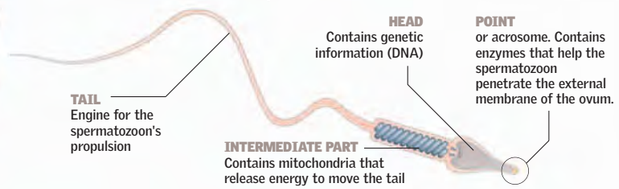
BLOOD VESSELS
are numerous, and they connect to the vas deferens.

DEFERENT DUCT (DUCTUS DEFERENS)
Connects the epididymis with the seminal vesicle

EPIDIDYMIS
The tube where the semen matures and enters the deferent duct

SEMINIFEROUS TUBE
Semen is produced here. Each testicle has thousands of them.

SPERMATOZOON Male reproductive cell



HEAD
Contains genetic information (DNA)

POINT
or acrosome. Contains enzymes that help the spermatozoon penetrate the external membrane of the ovum.

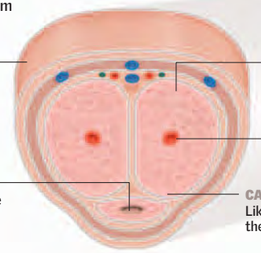
TAIL
Engine for the spermatozoon's propulsion

INTERMEDIATE PART
Contains mitochondria that release energy to move the tail

Internal Structure of the Penis

The most characteristic organ of a man's body, the penis has a cylindrical form with a double function for the urinary system and the reproductive system. In its normal, or relaxed, state the penis carries urine from the body via the urethra during urination. In its erect state its rigidity permits it to be introduced into the female vagina and to release sperm through ejaculation. The penis consists of spongy tissue supplied with blood vessels. The circulatory system supplies abundant blood to these vessels during sexual arousal so that the spongy tissue becomes swollen because of the filled blood vessels. This produces an erection, which makes copulation possible. The body of the penis surrounds the urethra and is connected to the pubic bone. The prepuce covers the head (glans) of the penis, which is located above the scrotum.

THE PENIS
transfers the sperm to the woman.



EXTERNAL SKIN
Covers the whole organ

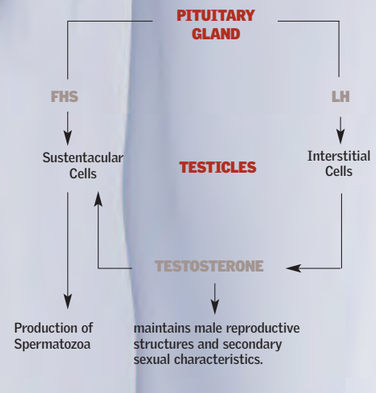
SPONGY TISSUE
Swells when it fills with blood, sustaining the erection

ARTERY
Its dilation causes the erection.

URETHRA
Extends through the spongy tissue

CAVERNOUS BODIES
Like the spongy tissue, these also fill with blood.`

THE GLANDS



Prostate and Epididymis

The prostate is a gland located in front of the rectum and below the bladder. It is the size of a walnut, and it surrounds the urethra, a tube that carries urine from the bladder. The prostate produces the liquid for the semen, which carries the spermatozoa. During orgasm, muscular contractions occur that send the liquid from the prostate out through the urethra. The epididymis is a duct that, when stretched out to its full length, is approximately 20 feet (5 m) long. In the male body it is extremely coiled and lies on the back surface of the testicles, where it is connected with the corresponding vas deferens. The vas deferens stores spermatozoa and provides them with an exit route. The seminal vesicles are two membranous receptacles that connect to both sides of the vas deferens and form the ejaculatory duct.

150 million

THE NUMBER OF SPERMATOZOA THAT EACH 0.06 CUBIC INCH (1 ML) OF SEMEN CAN CONTAIN

BLADDER
Receptacle of the urinary system that temporarily stores urine

93° F (34° C)

IS THE IDEAL APPROXIMATE TEMPERATURE REQUIRED BY THE TESTICLES TO PRODUCE SEMEN. It is lower than the normal body temperature of 98.6° F (37° C) because that temperature would be too warm for this function. This explains why the testicles are outside of the body. Depending on the ambient temperature, they extend or retract.

PROSTATE
Gland that secretes a creamy liquid (semen) along with the ejaculated sperm

EJACULATORY DUCT
A short tube that carries the sperm to the urethra

SEMINAL VESICLE
Secretes fluid and assorted nutrients into the sperm during ejaculation

PREPUCE
Covers and protects the head of the penis

GLANS
Extremity of the penis

TESTICLE
Gland that produces sperm

SCROTUM
Sac of skin that contains the testicles

EPIDIDYMIS
Spiral tube where the sperm matures

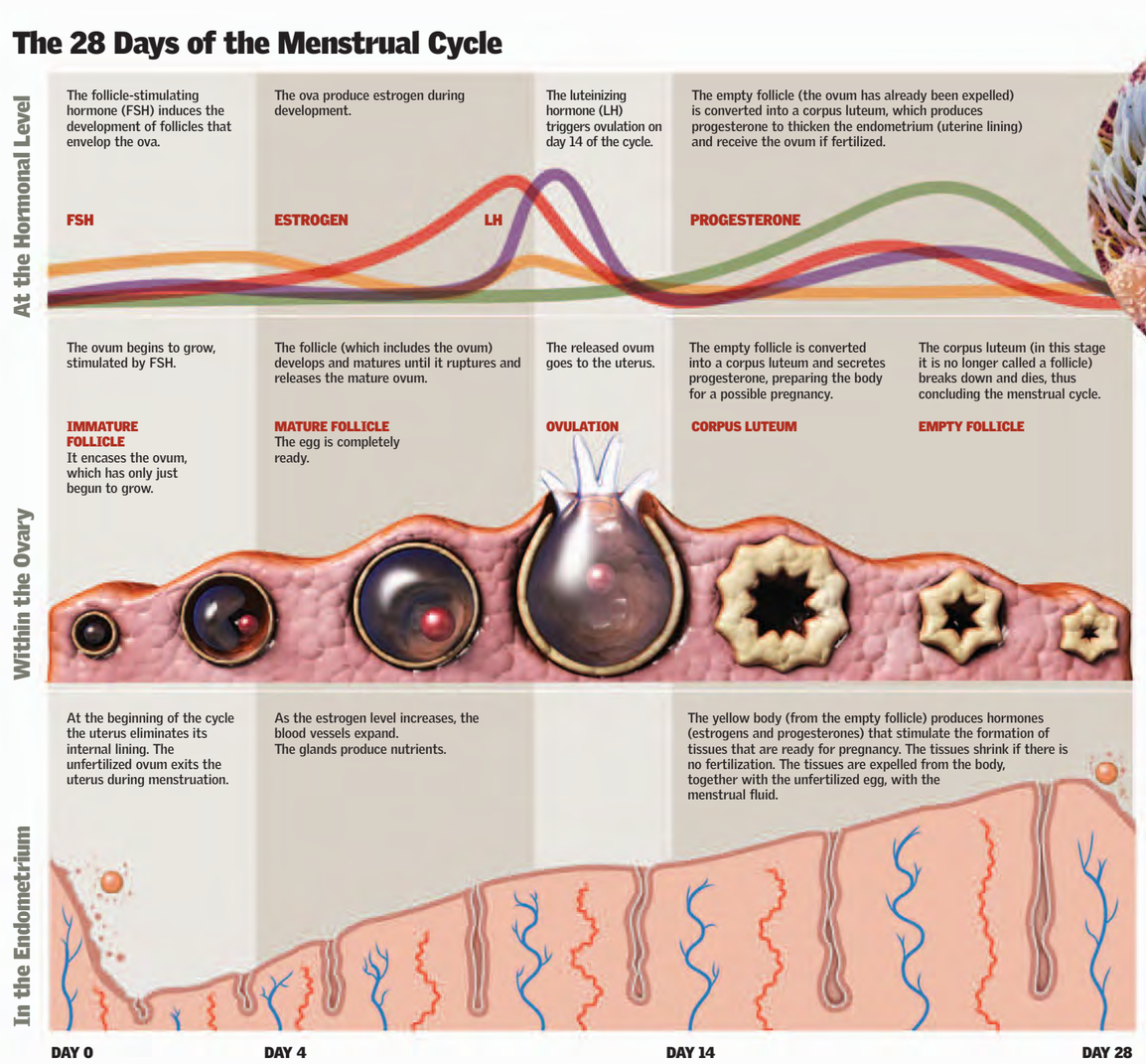
Female Reproductive System

Its primary function is the production of ova, and its organs are arranged so as to allow the fertilization of the ovum by a spermatozoon of the male reproductive system and from that moment to facilitate a series of processes known collectively as pregnancy for the creation of a new being. The internal organs of the female reproductive system are the vagina, the uterus, the ovaries, and the fallopian tubes. The external genitalia, generally referred to as the vulva, are relatively hidden and include the labia majora and minora, the clitoris, the urinary meatus, Bartholin's glands, and the vaginal orifice that leads to the vagina. The menstrual cycle governs the system's function. ●

2 million

IS THE APPROXIMATE NUMBER OF OVA THAT AN INFANT GIRL HAS IN HER BODY AT BIRTH. BETWEEN THE AGES OF 10 AND 14, ABOUT 300,000 TO 400,000 OVA REMAIN, OF WHICH ONLY 400 WILL MATURE COMPLETELY OVER HER LIFETIME.

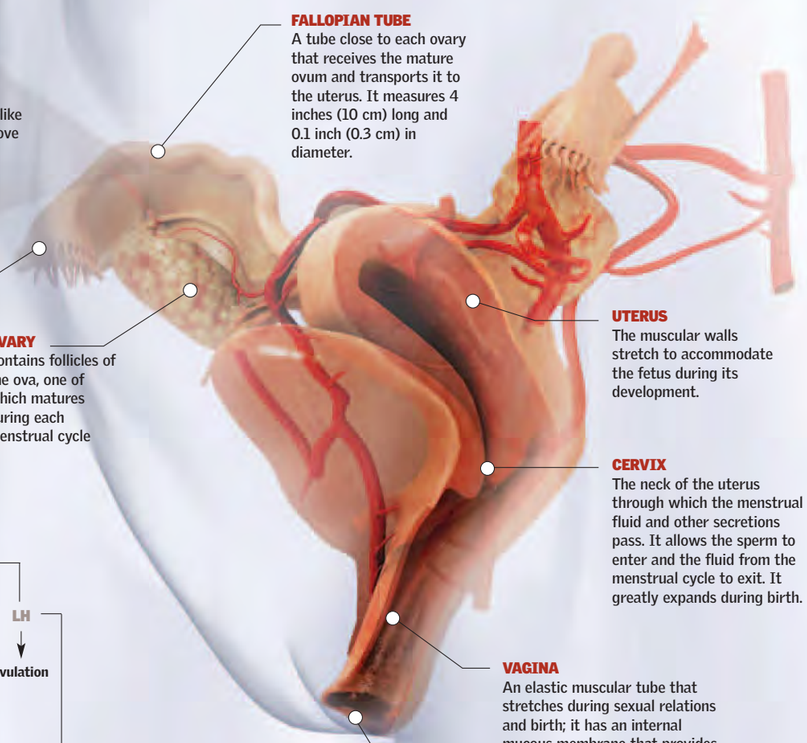
The 28 Days of the Menstrual Cycle



Cilia, tiny hairlike structures, move the ova very smoothly.

Menstruation: The Key to Female Reproduction

The female reproductive system is more protected than that of the male because the bony structure of the pelvis houses and shields it. Its development begins around the age of 10, when the female hormones begin a three- to four-year process during which the genital organs, the breasts, the pubic hair, and the general shape of the body change. Toward the age of 13, sometimes earlier or later, the first menstruation, called the menarche, occurs, signaling the beginning of a woman's fertility. She will normally remain fertile for several decades. During menopause, when fertilization is no longer possible, a woman's sexual life is usually not affected and can continue normally.



FALLOPIAN TUBE
A tube close to each ovary that receives the mature ovum and transports it to the uterus. It measures 4 inches (10 cm) long and 0.1 inch (0.3 cm) in diameter.

FIMBRIAE
Filamentary formations that guide the released ovum toward the fallopian tube during ovulation

OVARY
Contains follicles of the ova, one of which matures during each menstrual cycle

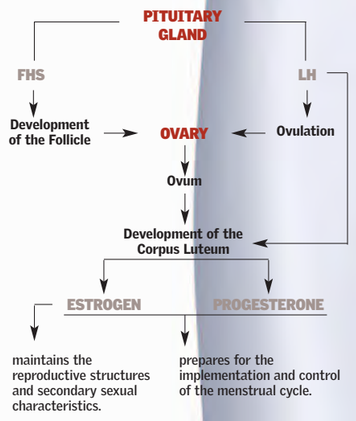
UTERUS
The muscular walls stretch to accommodate the fetus during its development.

CERVIX
The neck of the uterus through which the menstrual fluid and other secretions pass. It allows the sperm to enter and the fluid from the menstrual cycle to exit. It greatly expands during birth.

VAGINA
An elastic muscular tube that stretches during sexual relations and birth; it has an internal mucous membrane that provides lubrication and an acid medium that acts as a defense against infection. It serves as the pathway of the uterus to the exterior.

CLITORIS
A sensitive protuberance of tissue that responds to sexual stimulation

THE GLANDS



The Senses and Speech

HEALTHY AND SHINY SKIN
The health of the skin depends upon a diet that provides the organism with a sufficient amount of proteins and minerals.

SMELL AND TASTE 70-71
TOUCH AND THE SKIN 72-73
ANATOMY OF THE EYE 74-75
THE MECHANICS OF HEARING 76-77
SPEECH AND NONVERBAL LANGUAGE 78-79

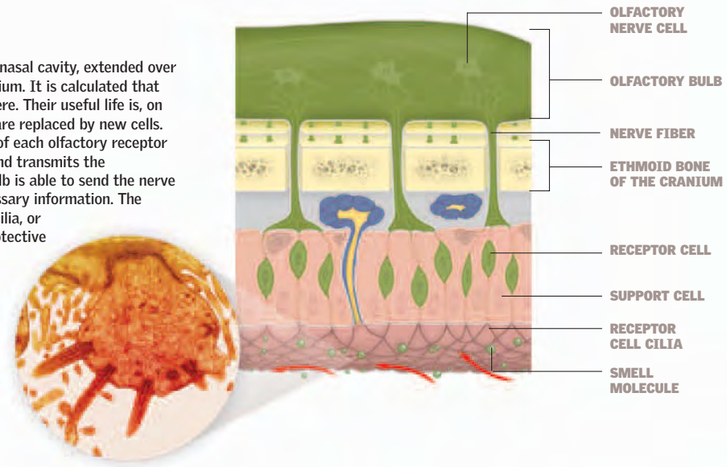
Everything we know about the world comes to us through the senses. Traditionally it was thought that we had only five: vision, hearing, touch, smell, and taste. However, for some time now we have known that we have many additional classes of sensations—such as pain, pressure, temperature, muscular sensation, and a sense of motion—that are generally included in the sense of touch. The areas of the brain involved are called somatosensory areas. Although we often take our senses for granted, each one of them is delicate and irreplaceable. Without them it is nearly impossible to understand our surroundings. They are a bridge between us and everything alive on the Earth. ●

Smell and Taste

These two senses of the body function as powerful allies of the digestive system. Taste involves the perception of dissolved chemical substances arriving, for example, in the form of food. Taste sensation is principally seated on the upper surface of the tongue, and saliva is a fundamental ingredient for dissolving and tasting. Smell involves the perception of these chemicals when they take the form of dispersed aromas. The sense of smell operates at a greater distance than that of taste and can capture substances floating in the environment. It is thought that smell is some 10,000 times more sensitive than any of our other senses.

Olfactory Cells

These are located deep in the nasal cavity, extended over the so-called olfactory epithelium. It is calculated that some 25 million cells are located there. Their useful life is, on average, 30 days, after which they are replaced by new cells. They have a dual function. One end of each olfactory receptor is connected to the olfactory bulb and transmits the sensations it records, so that the bulb is able to send the nerve impulses to the brain with the necessary information. The other end terminates in a group of cilia, or microscopic hairs, which serve a protective function within the mucosa.



10,000

THE NUMBER OF ODORS THE SENSE OF SMELL CAN DISTINGUISH

Gustatory Papillae

The tongue is the principal seat of the sense of taste. It has great mobility at the bottom of the mouth and contains between 5,000 and 12,000 gustatory papillae. Each of these papillae has approximately 50 sensory cells, which have an average life span of 10 days. The salivary glands are activated by the ingestion of food or just before ingestion. They generate an alkaline liquid called saliva, a chemical solvent that, together with the tongue, breaks down the substances of which food is composed and makes it possible to differentiate between them by taste. The tongue takes charge of perceiving these tastes via the fungiform papillae, which give the tongue its rough appearance.

4 Flavors

THE SURFACE OF THE TONGUE CAN DISTINGUISH: SWEET, SALTY, SOUR, AND BITTER.

Touch and the Skin

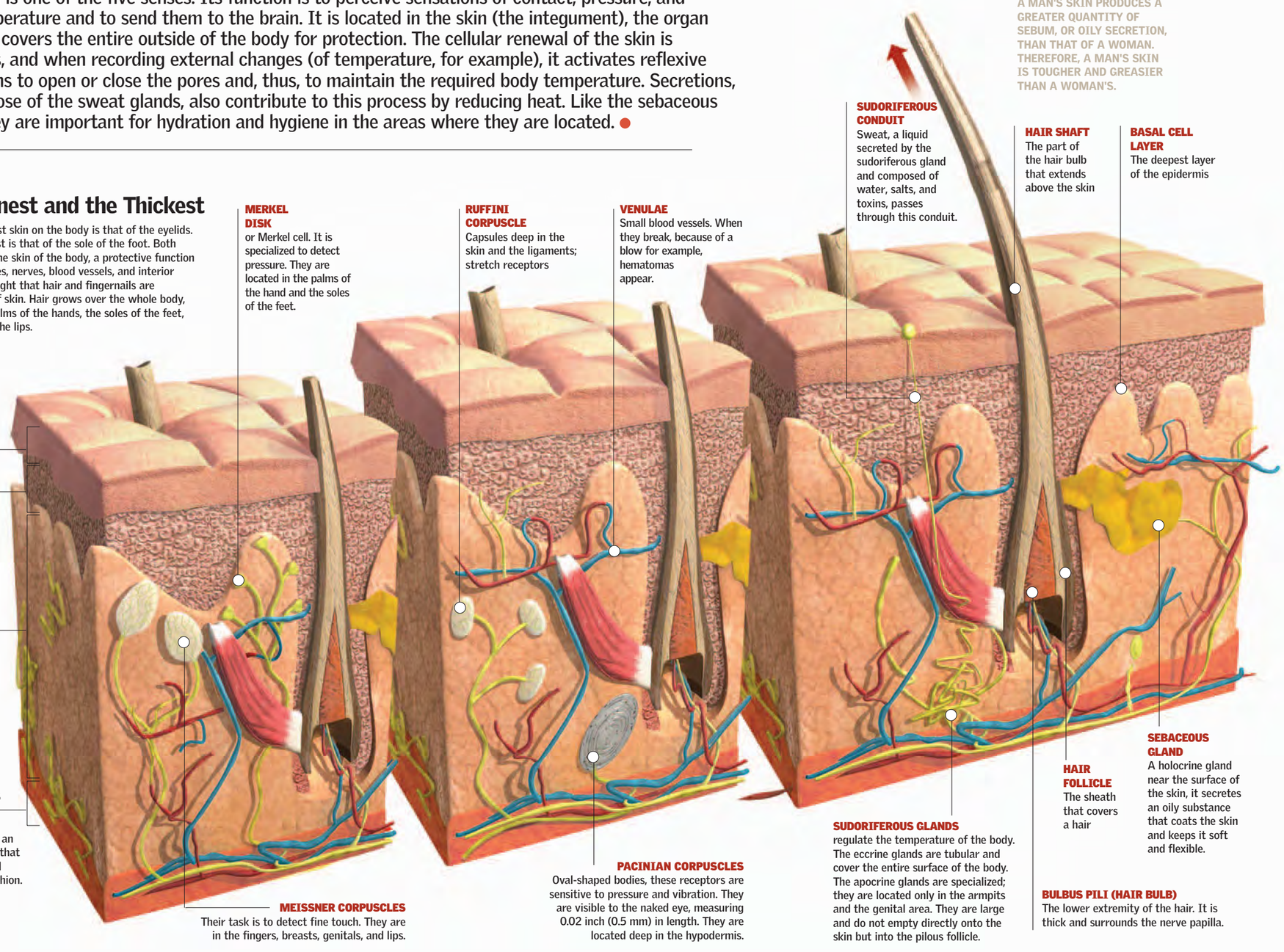
Touch is one of the five senses. Its function is to perceive sensations of contact, pressure, and temperature and to send them to the brain. It is located in the skin (the integument), the organ that covers the entire outside of the body for protection. The cellular renewal of the skin is continuous, and when recording external changes (of temperature, for example), it activates reflexive mechanisms to open or close the pores and, thus, to maintain the required body temperature. Secretions, such as those of the sweat glands, also contribute to this process by reducing heat. Like the sebaceous glands, they are important for hydration and hygiene in the areas where they are located.

The Thinnest and the Thickest

The thinnest skin on the body is that of the eyelids. The thickest is that of the sole of the foot. Both provide, like all the skin of the body, a protective function for muscles, bones, nerves, blood vessels, and interior organs. It is thought that hair and fingernails are modified types of skin. Hair grows over the whole body, except for the palms of the hands, the soles of the feet, the eyelids, and the lips.

Skin

A MAN'S SKIN PRODUCES A GREATER QUANTITY OF SEBUM, OR OILY SECRETION, THAN THAT OF A WOMAN. THEREFORE, A MAN'S SKIN IS TOUGHER AND GREASIER THAN A WOMAN'S.



UPPER SQUAMOUS LAYER
or hornlike layer. It is superficial, granulated, and transparent.

EPIDERMIS
Impermeable to water. It is external and is the thinnest layer. It is wear-resistant.

DERMIS
The middle layer, which is below the epidermis and is thicker

SUBCUTANEOUS FAT
Also called the hypodermis. It is an energy reservoir that acts as a thermal insulator and cushion.

MERKEL DISK
or Merkel cell. It is specialized to detect pressure. They are located in the palms of the hand and the soles of the feet.

MEISSNER CORPUSCLES
Their task is to detect fine touch. They are in the fingers, breasts, genitals, and lips.

RUFFINI CORPUSCLE
Capsules deep in the skin and the ligaments; stretch receptors

VENULAE
Small blood vessels. When they break, because of a blow for example, hematomas appear.

PACINIAN CORPUSCLES
Oval-shaped bodies, these receptors are sensitive to pressure and vibration. They are visible to the naked eye, measuring 0.02 inch (0.5 mm) in length. They are located deep in the hypodermis.

SUDORIFEROUS CONDUIT
Sweat, a liquid secreted by the sudoriferous gland and composed of water, salts, and toxins, passes through this conduit.

HAIR SHAFT
The part of the hair bulb that extends above the skin

BASAL CELL LAYER
The deepest layer of the epidermis

SUDORIFEROUS GLANDS
regulate the temperature of the body. The eccrine glands are tubular and cover the entire surface of the body. The apocrine glands are specialized; they are located only in the armpits and the genital area. They are large and do not empty directly onto the skin but into the pilous follicle.

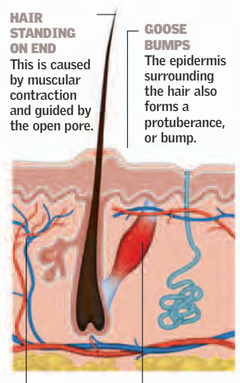
HAIR FOLLICLE
The sheath that covers a hair

BULBUS PILI (HAIR BULB)
The lower extremity of the hair. It is thick and surrounds the nerve papilla.

SEBACEOUS GLAND
A holocrine gland near the surface of the skin, it secretes an oily substance that coats the skin and keeps it soft and flexible.

Responding to Temperature

When the skin perceives the sensation of cold, the blood vessels and the muscles contract. The purpose of this is to prevent the escape of heat; as a consequence, the hairs stand on end, resulting in what is commonly called goose bumps. The opposite happens in response to heat: the blood vessels dilate because the skin has received instructions from the brain to dissipate heat, and the vessels emit heat as if they were radiators. The sudoriferous glands exude sweat onto the surface of the skin. The evaporation of sweat removes heat from the skin.

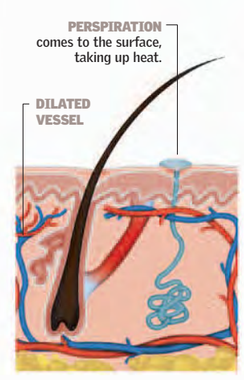


HAIR STANDING ON END
This is caused by muscular contraction and guided by the open pore.

GOOSE BUMPS
The epidermis surrounding the hair also forms a protuberance, or bump.

CONTRACTED VESSEL

CONTRACTED MUSCLE



PERSPIRATION
comes to the surface, taking up heat.

DILATED VESSEL

SUDORIFEROUS GLAND
secretes sweat, which rises to the surface of the epidermis.

A COLD
As with fear, cold puts a person's hair on end—literally! The contraction of both the blood vessels and the muscles causes the hair on the skin to stand on end.

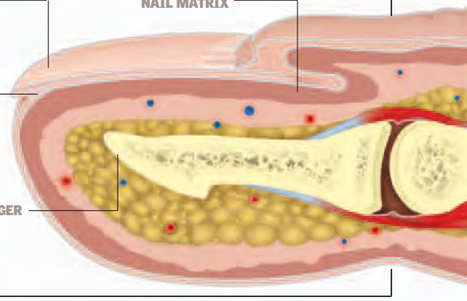
B HEAT
causes the secretion of sweat, which increases as the temperature rises. Cooling is caused by the evaporation of the sweat, which carries heat away from the body.

Nails

They are hard and hornlike. Their principal component is keratin, a protein that is also present in the skin and the hair. Their function is to cover and protect the ends of the fingers and toes. Their cells arise from the proliferative matrix and advance longitudinally. Once outside the body, they die. That is why there is no pain when you cut them.

A SHIELD FOR THE FINGERS AND TOES

The fingernail can be seen with the unaided eye, but the protective structure of the fingers and toes also includes their matrix and bone structure.



NAIL
The cells called corneocytes are full of keratin.

ROOT
The keratinization process pushes the cells outward, toward the nail.

A BONE OF THE FINGER

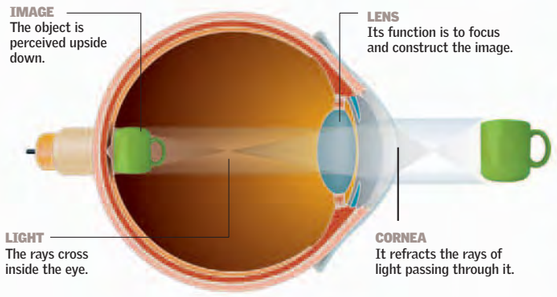
NAIL MATRIX

Anatomy of the Eye

Almost all the information that comes from the world into the brain depends on vision. The eye, one of the most complex organs of the body, allows us to judge the size and texture of an object even before we touch it or to know how far away it is. More than 100 million cells are activated instantaneously in the presence of light, converting the image perceived into nerve impulses that are transmitted to the brain. For this reason 70 percent of all the body's sensory receptors are concentrated in the eyes. It is vital that the brain receive information in a correct form: otherwise, things would appear to be distorted.

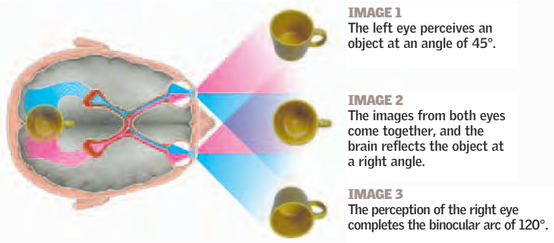
How Does the Eye See?

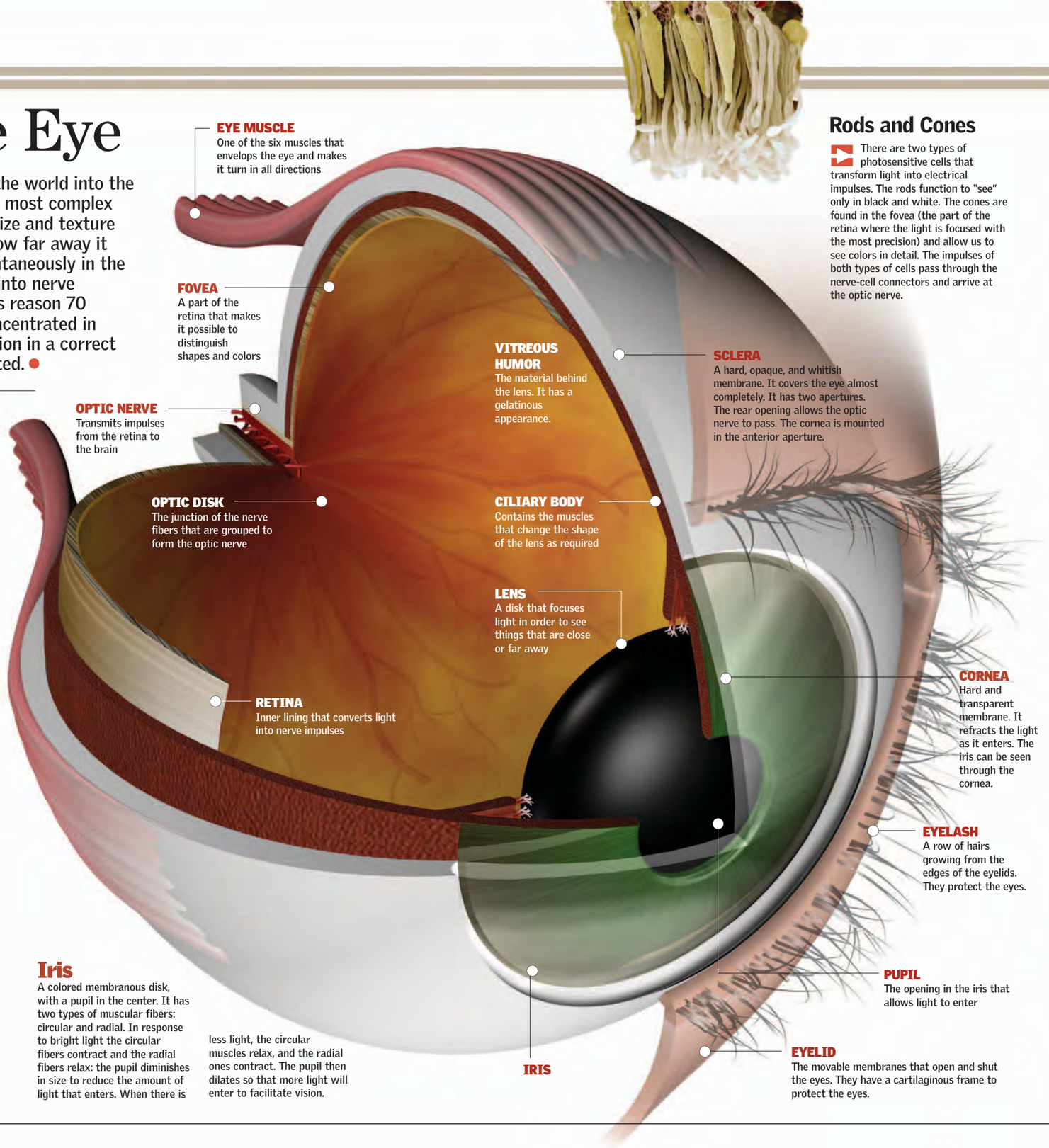
An object reflects light in all directions. The light is partially focused by the cornea, which refracts the entering rays. The lens focuses the rays of light, changing its shape to give the light the focus it needs. The rays cross the inside of the eye. The light arrives at the retina, and the rays perceived produce an inverted image of the object. The retina sends this information to the brain, which processes it and constructs a correct image of the object. Thanks to the fovea the eye can perceive details such as the shape and color of objects.



Seeing in Three Dimensions

When the eyes look ahead, the field of vision is binocular because both eyes see at the same time, each one from a different perspective. The images are superimposed at an angle of approximately 120°. This allows stereoscopic vision (two images of the same object from different angles, without deformation). The brain perceives the image in three dimensions.





Iris

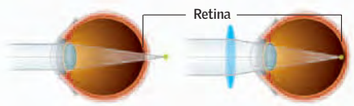
A colored membranous disk, with a pupil in the center. It has two types of muscular fibers: circular and radial. In response to bright light the circular fibers contract and the radial fibers relax: the pupil diminishes in size to reduce the amount of light that enters. When there is less light, the circular muscles relax, and the radial ones contract. The pupil then dilates so that more light will enter to facilitate vision.

Rods and Cones

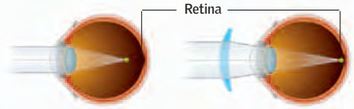
There are two types of photosensitive cells that transform light into electrical impulses. The rods function to "see" only in black and white. The cones are found in the fovea (the part of the retina where the light is focused with the most precision) and allow us to see colors in detail. The impulses of both types of cells pass through the nerve-cell connectors and arrive at the optic nerve.

VISION PROBLEMS

The most common problems involve seeing things out of focus. These are hypermetropia and myopia. Both can be corrected by the use of lenses. A hereditary condition called color blindness, or Daltonism, is less frequent.



A HYPEROPIA (FARSIGHTEDNESS)
This condition makes it difficult to see objects that are close to us. It happens when the image is focused behind the retina. It can be corrected by convex (converging) lenses, which make the rays of light strike the retina properly.

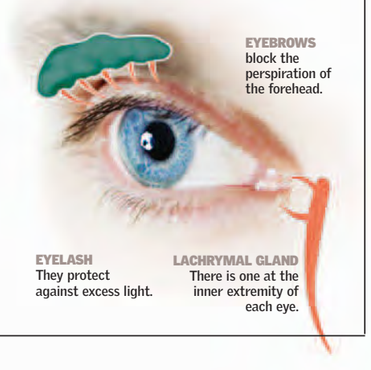


B MYOPIA (NEARSIGHTEDNESS)
Here the image is formed in front of the retina. This usually occurs when the ocular sphere is longer than normal. The myopic person has difficulty seeing distant objects. Myopia is corrected with concave (diverging) lenses or by an operation using a laser.

C COLOR BLINDNESS
Persons who are color blind have problems distinguishing between certain colors. It is a hereditary illness caused by the absence of the types of cone cells that are sensitive to yellow, green, or blue.

Protection

THE EYELIDS PROTECT THE EYES FROM BRIGHT LIGHT AND DUST. THE EYELASHES REDUCE EXCESS LIGHT. THE EYEBROWS KEEP SWEAT OUT OF THE EYES. THE NASOLACHRYMAL DUCT TAKES THE TEARS FROM THE NASAL CAVITY TO THE LACHRYMAL DUCTS—THE OPENINGS AT THE EXTREMITIES OF THE EYES—WHERE THEY ARE SECRETED.



Mechanics of Hearing

The ear is the sense responsible for hearing and maintaining equilibrium. When the ear perceives sounds, it registers its characteristics—volume, tone, and timbre—as well as the direction from which it comes. A group of nerve terminals receives information about the body's motion and transmits this to the brain in order to maintain dynamic and static equilibrium. The ear is important for communication by means of speech or other means, such as music. The ear is capable of distinguishing a great range of volumes, from the buzzing of a mosquito to the roar of an airplane. The ear contains the smallest bones of the body.

Frequencies

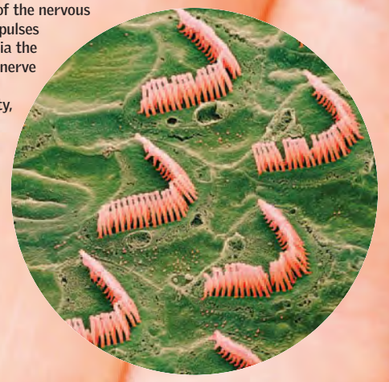
The frequency of a sound is the speed at which the sound makes the air vibrate. It is measured in units called hertz (Hz): one hertz corresponds to one vibration per second. High frequencies correspond to high sounds, and low frequencies to low sounds. The human ear can hear sounds between 20 and 20,000 vibrations per second.

FREQUENCIES AUDIBLE TO HUMANS AND ANIMALS

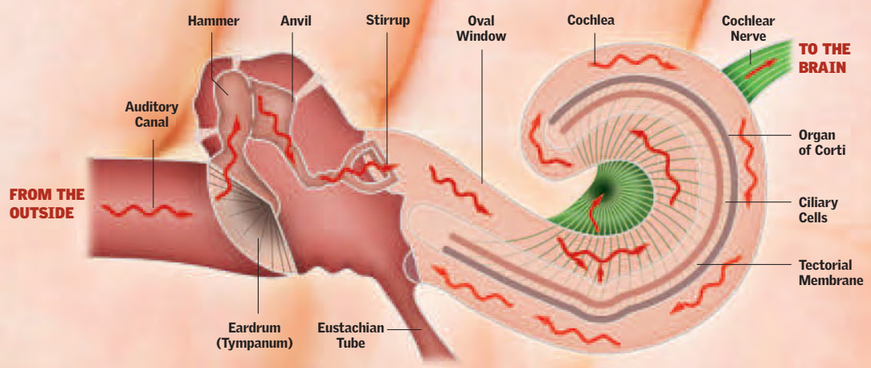
SUBJECT	MINIMUM	MAXIMUM
Person 10 years old	20 Hz	20,000 Hz
Person 60 years old	20 Hz	12,000 Hz
Dog	60 Hz	45,000 Hz
Frog	100 Hz	3,000 Hz
Bat	1,000 Hz	120,000 Hz
Cat	60 Hz	65,000 Hz

Organ of Corti

Contains ciliary cells that collect vibrations and transform mechanical energy into energy of the nervous system. Next the impulses arrive at the brain via the cochlear nerve. The nerve cells do not have a regenerative capacity, so if they are lost hearing will be lost along with them.



THE PROCESSING OF SOUND



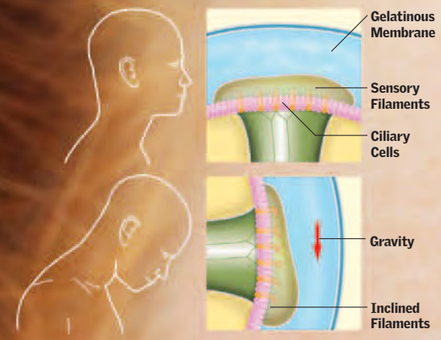
1 ENTRANCE
The sound wave is captured by the ear and enters via the auditory canal.

2 VIBRATION
The tympanum registers the intensity of the wave.

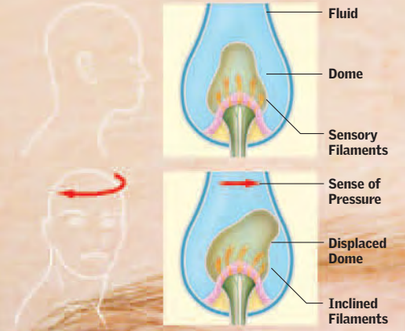
3 TRANSMISSION
The vibration of the eardrum is transmitted to the hammer, from the hammer to the anvil, from the anvil to the stirrup, from the stirrup to the oval window, from there to the cochlea, and from there to the cochlear nerve, whose electrical impulses are transmitted to the brain.

Equilibrium

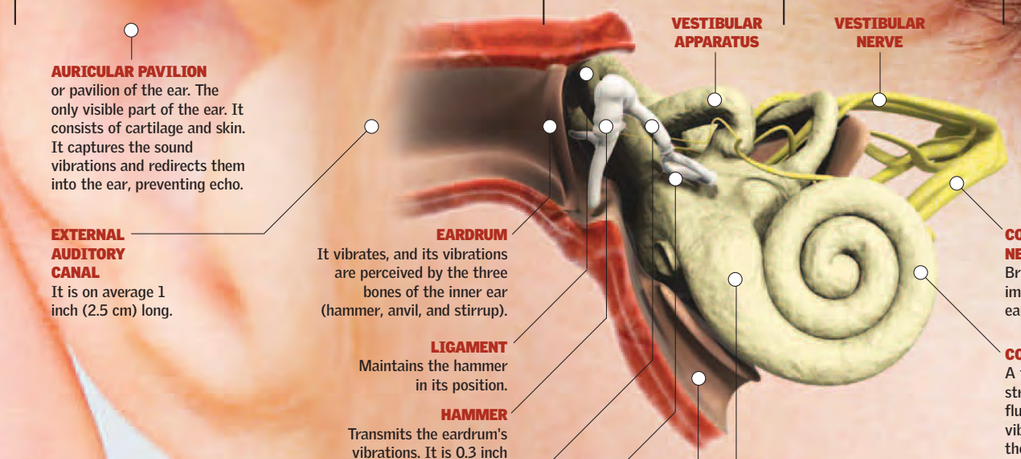
Dynamic and static equilibrium are maintained by the inner ear. Above the cochlea there are three semicircular canals, which are spiral-shaped conduits. Inside the canals are a gelatinous membrane and thousands of cilia, or hairlike structures, traversed by a cranial nerve that connects them to the brain. When the head moves, this gelatinous membrane is displaced, and the tiny cilia send the brain information about the velocity and the direction of this displacement. On that basis the body can move as required to maintain equilibrium. Excessive motion produces seasickness, because the cilia continue to move even when the motion stops.



LINEAR MOTION
The displacement of the gelatinous membrane, caused by a difference in height, changes the structure of the auditory cilia.



ROTATIONAL MOTION
The gelatinous membrane takes on the shape of a dome so that lateral motion will also disturb its equilibrium.



Speech and Nonverbal Language

Speaking is the verbal expression of a language and includes articulation, which is the manner in which words are formed. However, one can make oneself understood by means other than the spoken word, such as with signs, facial expressions, or gestures. These are examples of what is called nonverbal communication, whereby even silence can be expressive.

Language and Speech

Linguists explain that the organs of speech necessary to express language in sounds, which constitute the fundamental elements of speech, are just as independent of language as a telegraph apparatus is of the Morse code it transmits. Linguists also compare language (the verbal system of communication that is almost always written) with a symphony whose score exists independently of the musicians who play it.

The vocal cords behave like instruments. They are folds of muscle that open and close to produce sounds. When they are not producing vocal sounds, normal breathing occurs. Under the control of the brain, the vocal cords produce sounds that are modified by the lips and the tongue to create speech.

NASAL CAVITY
Adds resonance to speech

ORAL CAVITY
Acts like a resonance chamber

TONGUE
By changing its shape and position, the tongue varies the sounds produced.

ESOPHAGUS
In its respiratory function it brings in air, which is pushed by the diaphragm.

LIPS
modify sounds by changing their shape.

LARYNX
Contains the vocal cords

TRACHEA
Influences speech because the air passes through it

A Passage of Air
The vocal cords relax and open to allow air to pass to and from the lungs. No sound is produced because the vocal cords do not vibrate, which is the basis for sound.

B Sound Is Produced.
The vocal cords stretch horizontally above the larynx. They tighten when air flows past them. Sound is the vibration of the vocal cords.

Language of Gesture

The expressivity of the human face is the result of more than 30 muscles that tense small areas of the skin when they contract. Most of them operate in pairs. Their use is reflexive in most cases, as in the gestures, facial expressions, and grimaces that often accompany the spoken word and are silent expressions in certain situations. In other cases, however, such as the art of acting, their use and mastery can be studied and practiced. The usual example of this is the art of mimes, who can stage complete dramas that are transmitted very effectively with no recourse to the spoken word or use of the voice.

Broca
Controls the articulation of speech.

Visual
Receives and analyzes the nerve impulses from the eye.

Wernicke
Controls the comprehension of language.

FACIAL EXPRESSIONS
The muscles of the face also serve to communicate feelings.

FROWNING
Action of the corrugator muscles on the eyebrows

SURPRISE
The muscles of the forehead are contracted.

SMILE
Action of the smile muscles and the zygomaticus major

Control Centers

NERVE CELLS
Microscope photograph of a group of neurons

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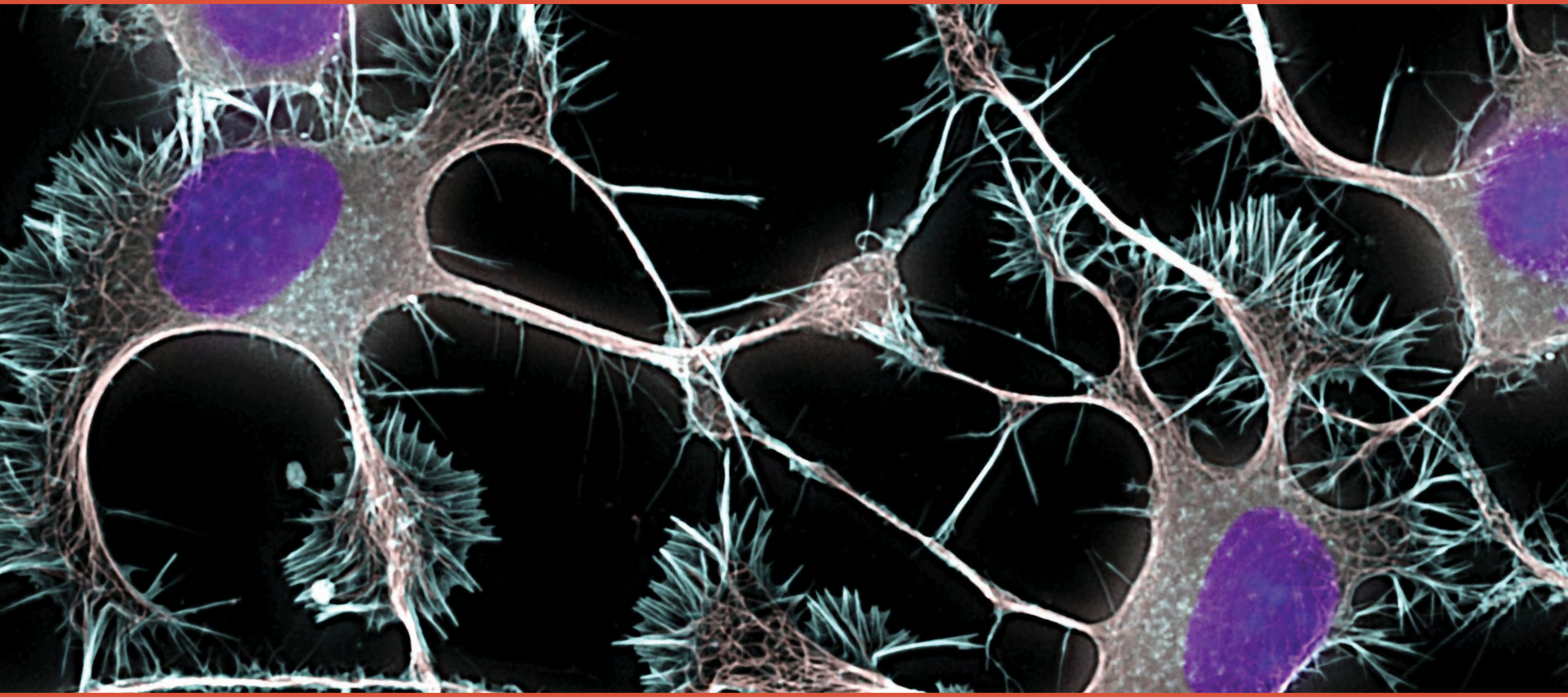


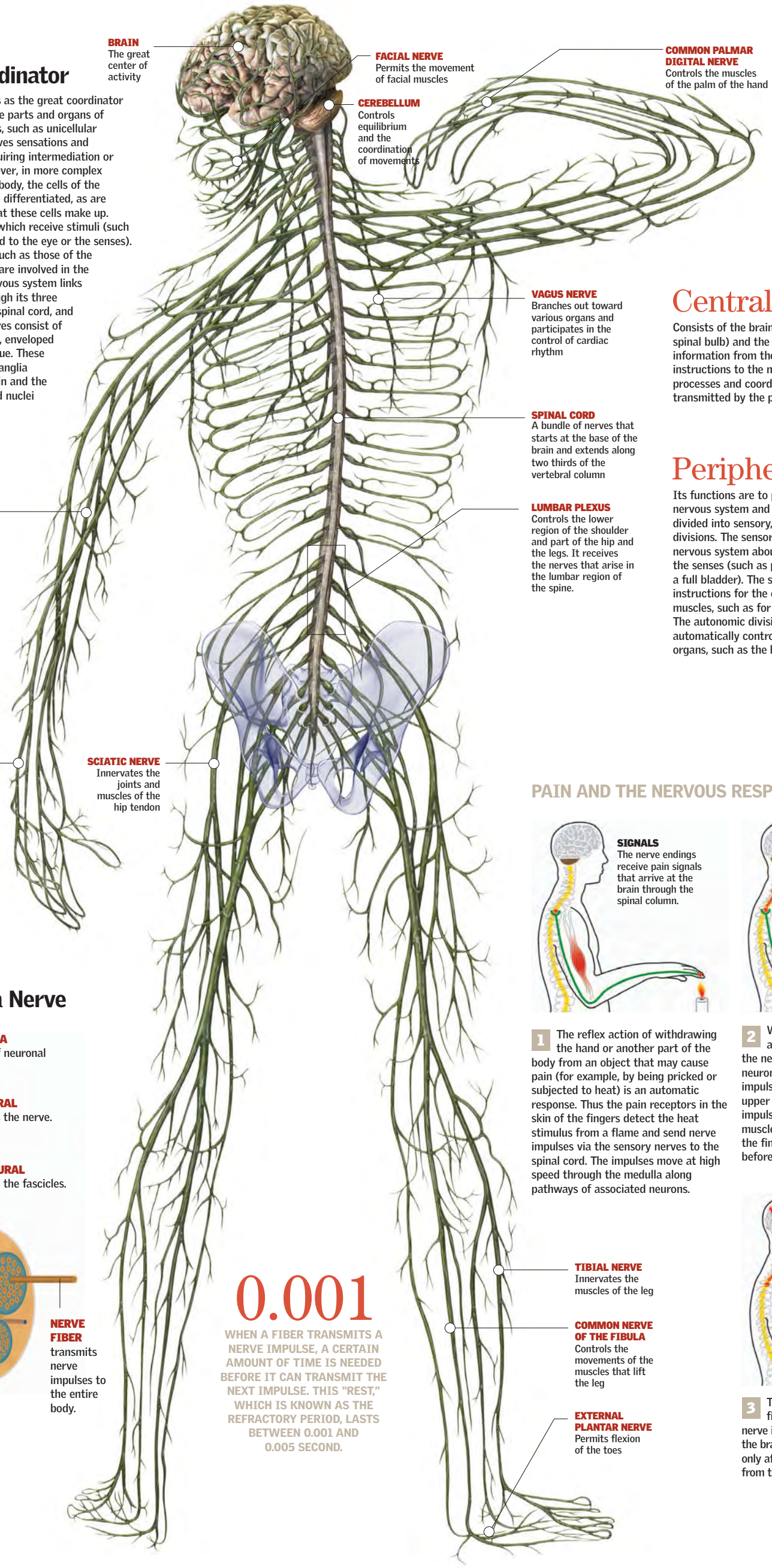
Brain tissue consists of thousands of millions of neurons that continually send each other signals through connections called synapses. Thanks to this network the brain can remember, calculate, decide, think, dream, create, and express emotions. We invite you to understand the secrets about how these activities of the brain are accomplished. What determines the formation of synapses and neuronal networks? Where are intelligence and memory located? Is it possible to stimulate brain cells? What happens during a dream? What are nerves, and how are they formed? What functions are carried out by each region of the brain? You will find all this and much more in this chapter, including incredible images.

Nervous System

The body's most complex system, many of whose characteristics and potentialities are still unknown. Together with the endocrine system, the brain has the job of controlling the organism. Its specific functions are rapid and intellectual activities, such as memory, emotions, and will. The brain is divided into three portions: the central (the brain and the spinal cord), the peripheral (nerves of the spinal cord and cranium), and the vegetative (or autonomic function). ●

The Great Coordinator

The nervous system acts as the great coordinator of the functions of all the parts and organs of the body. In simpler organisms, such as unicellular organisms, the same cell receives sensations and responds to them without requiring intermediation or specialized coordination. However, in more complex organisms such as the human body, the cells of the different parts of the body are differentiated, as are the functions of the organs that these cells make up. Thus there are receptor cells, which receive stimuli (such as the cells of the organs linked to the eye or the senses). There are also effector cells (such as those of the muscles or the glands), which are involved in the organism's responses. The nervous system links these functions together through its three principal parts: the brain, the spinal cord, and the nerves in general. The nerves consist of numerous axons and dendrites, enveloped by a sheath of conjunctive tissue. These groups of neurons are called ganglia when they are outside the brain and the spinal cord, and they are called nuclei when they are inside.



300 feet (90 m) per second

THE SPEED AT WHICH IT IS CALCULATED THAT A NERVE IMPULSE TRAVELS IN A NERVE WITH A MYELINATED SHEATH

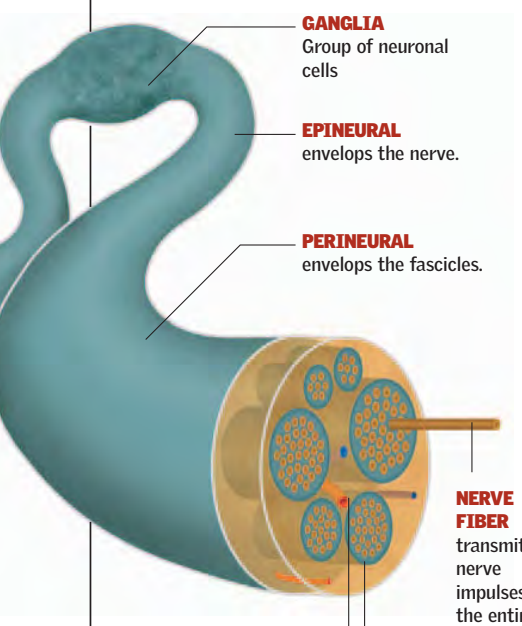
Central

Consists of the brain (cerebrum, cerebellum, and spinal bulb) and the spinal column. It receives information from the sense organs and sends instructions to the muscles and other organs. It also processes and coordinates the nervous signals transmitted by the peripheral system.

Peripheral

Its functions are to provide information to the central nervous system and to coordinate movements. It is divided into sensory, somatic, and autonomic divisions. The sensory division informs the central nervous system about external changes detected by the senses (such as pain) or internal changes (such as a full bladder). The somatic division sends instructions for the conscious movement of different muscles, such as for shaking hands or kicking a ball. The autonomic division (vegetative nervous system) automatically controls the functioning of the internal organs, such as the heart.

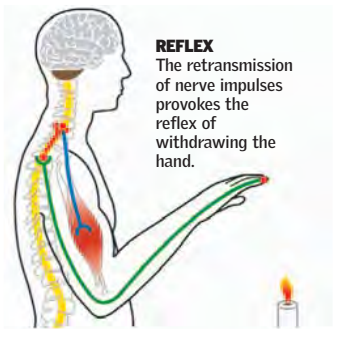
Structure of a Nerve



0.001

WHEN A FIBER TRANSMITS A NERVE IMPULSE, A CERTAIN AMOUNT OF TIME IS NEEDED BEFORE IT CAN TRANSMIT THE NEXT IMPULSE. THIS "REST," WHICH IS KNOWN AS THE REFRACTORY PERIOD, LASTS BETWEEN 0.001 AND 0.005 SECOND.

PAIN AND THE NERVOUS RESPONSE



1 The reflex action of withdrawing the hand or another part of the body from an object that may cause pain (for example, by being pricked or subjected to heat) is an automatic response. Thus the pain receptors in the skin of the fingers detect the heat stimulus from a flame and send nerve impulses via the sensory nerves to the spinal cord. The impulses move at high speed through the medulla along pathways of associated neurons.

2 Within thousandths of a second after detecting the pain stimulus, the nerve impulses reach the motor neurons. These neurons transmit the impulses to the flexor muscles in the upper part of the arm. Once the impulses have been received, the muscles contract, the arm bends, and the fingers move away from the flame before any pain is consciously felt.

3 The pain is felt when the nerve fibers in the spinal cord bring the nerve impulses to the sensory areas of the brain. The sensation of pain is felt only after the hand has been withdrawn from the fire by reflex action.

Neurons

Neurons are cells that make up the nervous system. Their function is to transmit impulses in the form of electrical signals carrying information to the brain and from there to the periphery. The neurons provide the basis for the system's activities and form a highly complex communication network. They are surrounded and protected by other nerve cells that are not excitable, called glial cells, which constitute more than half of all an organism's nerve cells.

Plasticity

Each neuron is essentially made up of a body, an axon, and many dendrites. The communication that is established among neurons resembles a conversation, or a continuous ongoing exchange of information. Until recently it was thought that neurons, unlike other tissue, could not be regenerated once lost. Today not only is it known that this is not so, but it is also known that the capabilities of the brain and the nervous system are more a function of the circuits and connections that are established among the neurons than of the number of neurons per se. These connections are activated, deactivated, and modified by very diverse factors (such as learning, food, habits, exercise, the effects of drugs and accidents). Some neurons can regenerate if they have been damaged.

SYNAPTIC NODE
The terminal point of the axon branch, it contains chemicals that transmit nerve impulses.

MYELIN SHEATH
A fatty layer that insulates the axons of some neurons in order to accelerate nerve impulse transmission. In the peripheral nervous system, this sheath consists of Schwann cells.

RANVIER'S NODE
An opening in the myelin sheath that aids in the transmission of nerve impulses

MITOCHONDRIA
provide energy to the cell.

AXON
Nerve fiber that transmits impulses

NUCLEUS
Contains the neuron's genetic material

SCHWANN CELL
A glial cell that surrounds an axon

CELL BODY
Generates the vital processes of the neuron cell

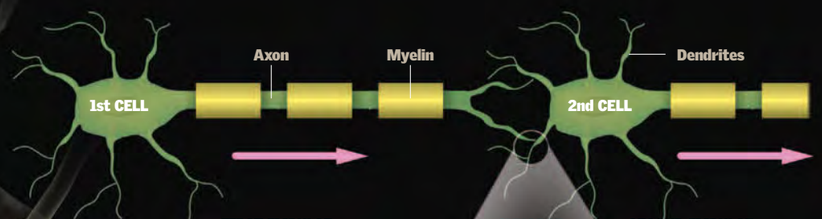
DENDRITE
Protuberance that captures signals from other neurons. A neuron can have about 200 dendrites; the number of dendrites varies from cell to cell.

100 billion
THE NUMBER OF INTERCONNECTED NEURONS IN A HUMAN BEING

500 million
IS THE NUMBER OF SYNAPSES (CONNECTIONS AMONG NEURONS) FORMED IN 0.06 CUBIC INCH (1 CU MM) OF A BRAIN'S NERVE TISSUE. OVERALL, THE BRAIN HAS 1 QUADRILLION SYNAPSES.

Transmission and Synapses

The synapse is the point of communication between neurons. It comprises a synaptic cleft, a synaptic knob, and a target to which the nerve signal is directed. In order for a neuron to be activated, there must be a stimulus that converts the electrical charge inside the membrane of the cell from negative to positive. The nerve impulse travels via the axon toward the synaptic knob and brings about the release of chemical substances called neurotransmitters. These in turn can elicit a response from the target to which the stimulus is directed.



FIRST IMPULSE
Received by the dendrites that transmit it to the axon

SYNAPSE

SECOND IMPULSE
The sequence repeats, maintaining its shape.

COMPONENTS OF THE SYNAPSE

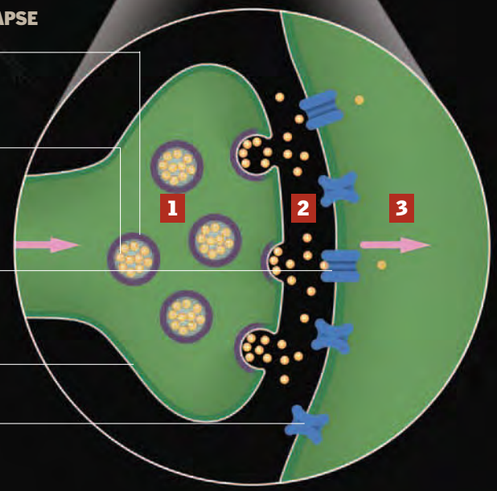
SYNAPTIC VESICLES
Sacs that contain neurotransmitter molecules brought to the synaptic cleft via calcium ions

NEUROTRANSMITTERS
Chemical molecules released by the synaptic vesicles toward the synaptic cleft. From there they influence the transmission of the impulse.

POINT OF RECEPTION
The neurotransmitter combines with protein receptors at the point of neuronal communication.

CELL MEMBRANE
The charge inside the cell membrane is negative.

MICROTUBULES
Structures that help transport neurotransmitter molecules to the synaptic membrane.



TRANSMISSION OF NERVE IMPULSES

1 Without Information
When the neuron is at rest, the sodium ions inside it are uniformly distributed so that the electrical charge inside the cell membrane is permanently negative.

2 The Impulse Arrives
The arrival of the neurotransmissions at the dendrites causes a reversal of the charge, which becomes positive in this area, giving it a tendency to move in the direction of the negatively charged part of the cell.

3 Transmission of Information
The positive charge travels toward the negatively charged axon until it reaches the synapse and thus the other cell. The areas it has left return to their stable (negative) state.

TYPES OF NEURONS ACCORDING TO THEIR COMPLEXITY

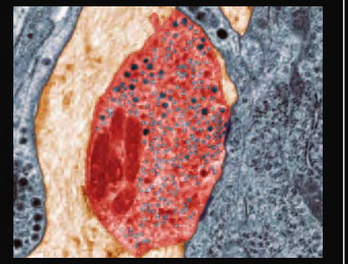
UNIPOLAR. Two branches of the same axon extend from one cell body.

BIPOLAR. Two separate axons extend from each end of a cell body.

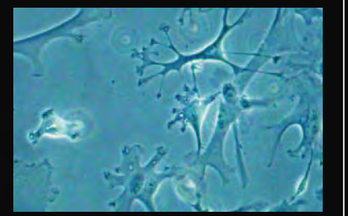
MULTIPOLAR. One axon and a number of dendrites extend from a cell body.

Neuromuscular Union

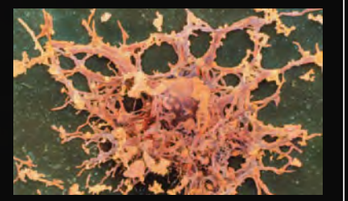
This is a special kind of synapse between the neurons and the skeletal muscle fibers that causes voluntary contraction of the muscles.



The axon of a neuron links itself with a muscle fiber. At the point of contact a chemical synapse is produced between the neuron and an effector, a muscle with electrically excitable tissue, and movement results.



ASTROCYTES are cells located in cerebral tissue, where they exceed neurons in number. Astrocytes have some delicate protuberances that are linked to the blood vessels and that regulate the flow of nutrients and waste between neurons and blood.



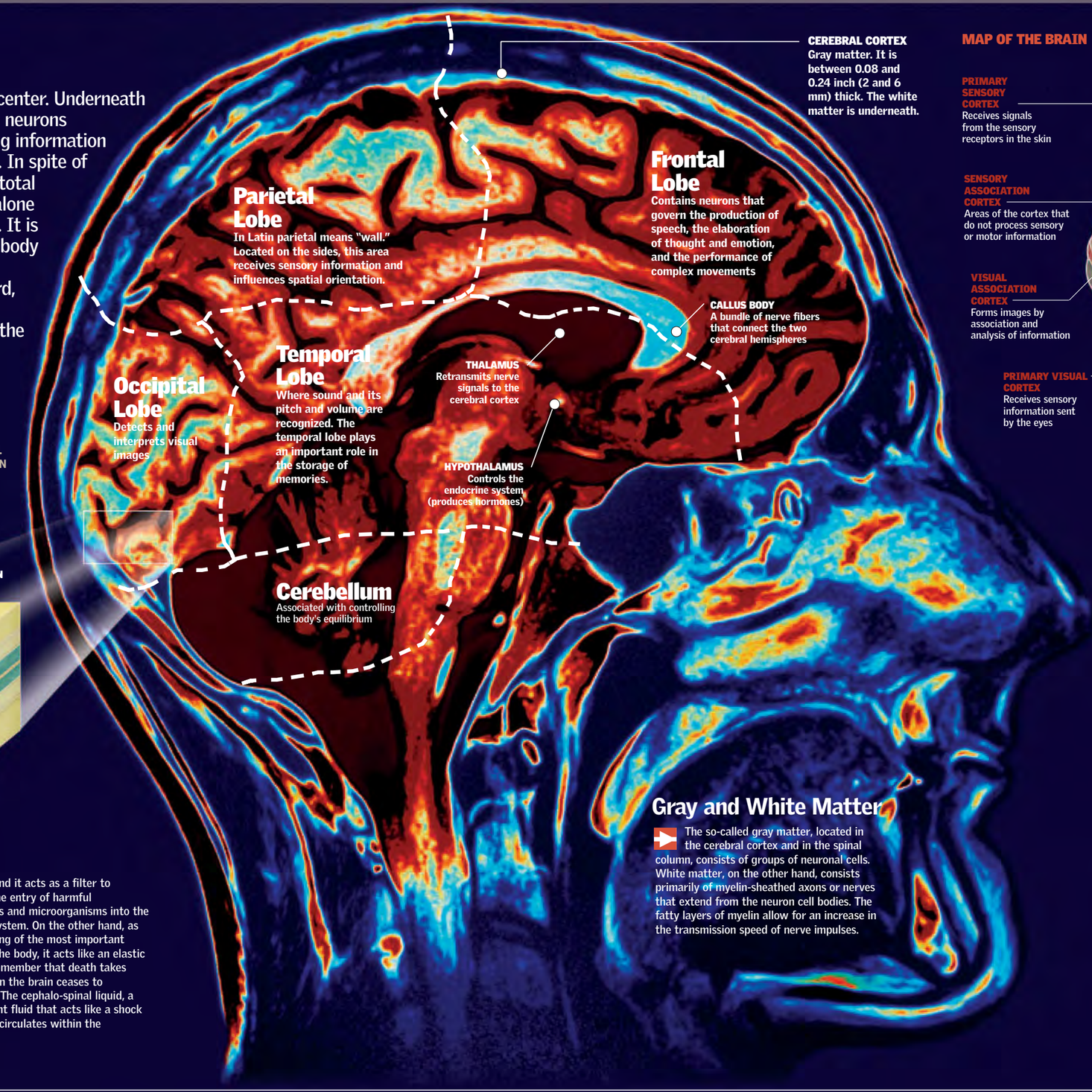
OLIGODENDROCYTES are the cells that form the myelin sheath around the nerve fibers of the brain and the spinal column. Their function is similar to that of Schwann cells in the peripheral nervous system

The Brain

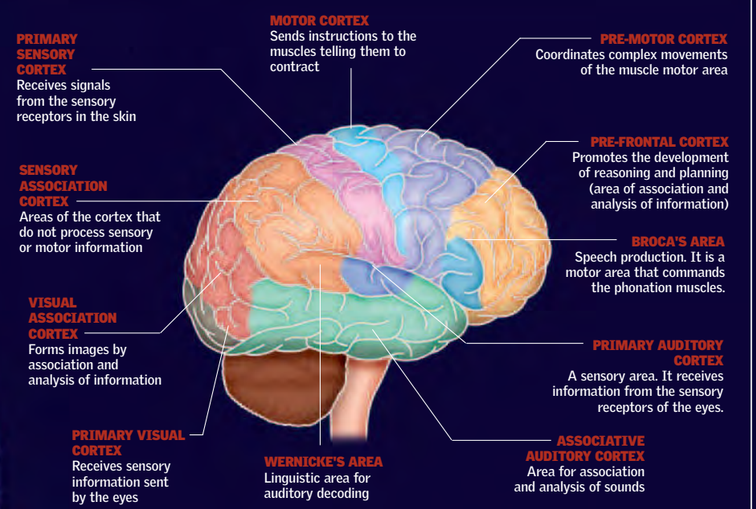
The brain is the body's control center. Underneath its folds more than 100 billion neurons organize and examine incoming information and act as a guide for the organism. In spite of amounting to only 2 percent of the total weight of a human body, the brain alone uses one fifth of the oxygen inhaled. It is one of the most fragile parts of the body and, therefore, one of the most protected. Along with the spinal cord, the brain forms the central nervous system, which gives instructions to the peripheral nervous system.

3 pounds (1.4 kg)

AVERAGE WEIGHT OF AN ADULT BRAIN. AT BIRTH THE BRAIN WEIGHS BETWEEN 12 AND 14 OUNCES (350 AND 400 G).

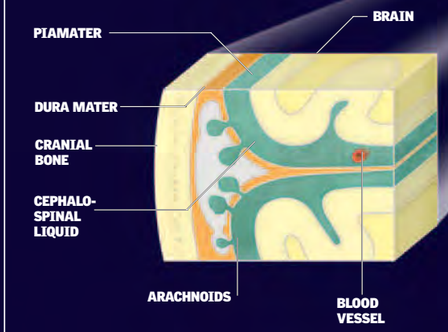


MAP OF THE BRAIN



MENINGES

Protective membranes covering the brain



Meninges

There are three membranes, called meninges, that cover the brain. The outermost one covers the inside of the cranium, and it contains veins and arteries that feed blood to the cranial bones. It is called dura mater. The middle membrane is known as the arachnoid and consists of netlike elastic connective tissue. The piamater, the thinnest of the three, is the closest to the surface of the cerebral cortex. Its functions are primarily protective.

On one hand it acts as a filter to prevent the entry of harmful substances and microorganisms into the nervous system. On the other hand, as the covering of the most important organ of the body, it acts like an elastic helmet (remember that death takes place when the brain ceases to function). The cephalo-spinal liquid, a transparent fluid that acts like a shock absorber, circulates within the meninges.

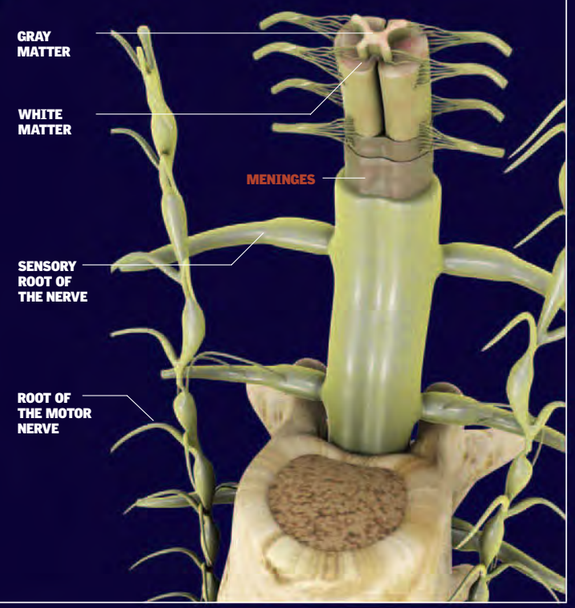
Gray and White Matter

The so-called gray matter, located in the cerebral cortex and in the spinal column, consists of groups of neuronal cells. White matter, on the other hand, consists primarily of myelin-sheathed axons or nerves that extend from the neuron cell bodies. The fatty layers of myelin allow for an increase in the transmission speed of nerve impulses.

Spinal Medulla

The spinal medulla is the spinal cord, which goes from the cephalic trunk to the lumbar region. Together with the brain it forms the central nervous system. It can reach a length of 18 inches (45 cm). It is composed of gray and white matter. The gray matter is located in its core, in tissue consisting essentially of neurons.

Surrounding the gray matter is white matter that contains the nerve fibers that transmit signals to and from the brain. The spinal nerves extend outward from the medulla to the body and its extremities. Paralysis in one or more parts of the body can result if the spinal cord is damaged.

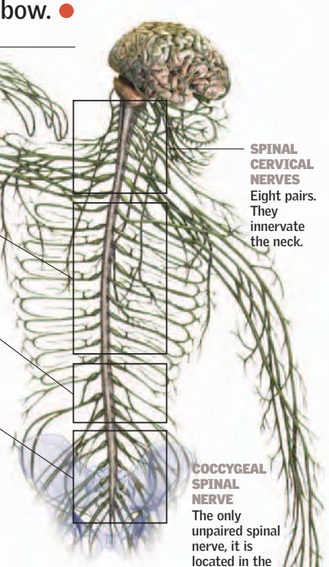


Peripheral Nerves

The peripheral nerves have the task of bringing information to and from the brain and spinal column. Depending on their location, they may be cranial or spinal nerves. The sensory fibers in the peripheral nerves receive information from the outside world, the skin, and the internal organs and transmit it to the central nervous system; the motor fibers begin to contract the skeletal muscles and transmit signals in the opposite direction from the sensors. The nerves are located deep in the body, with some exceptions, such as the cubital nerve in the elbow.

Spinal Nerves

There are 31 pairs of spinal nerves that begin at the spinal cord and extend through the spaces between the vertebrae. Each nerve is divided into numerous branches. These nerves control most of the body's skeletal muscles, as well as the smooth muscles and the glands. The cervical nerves serve the muscles of the chest and shoulders. The lumbar nerves serve the abdomen and part of the legs, and the sacral nerves control the rest of the legs and the feet.



SPINAL CERVICAL NERVES
Eight pairs. They innervate the neck.

THORACIC SPINAL NERVES
Twelve pairs. The anterior branch forms the intercostals.

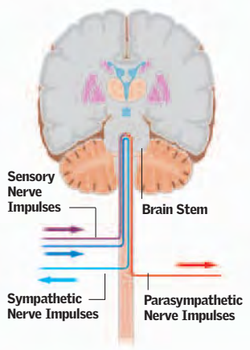
LUMBAR SPINAL NERVES
Five pairs. The last ones form the "horse's tail."

SACRAL SPINAL NERVES
Five pairs. They are located in the lowest segment of the spinal cord.

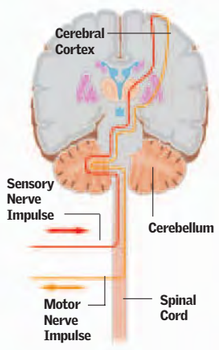
COCCYGEAL SPINAL NERVE
The only unpaired spinal nerve, it is located in the tailbone, or coccyx.

THE THREE RESPONSES

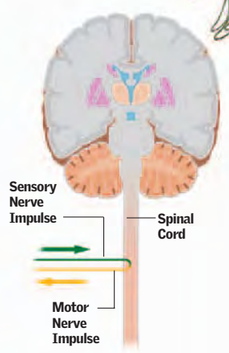
The nerve receptors gather information that goes to the cerebral cortex and to the spinal cord. The response can be automatic, ordering dilation or contraction. Voluntary response implies a complex nerve path. Reflex responses are simpler; some of them are processed in the brain, but most of them are processed in the spinal cord.



A AUTOMATIC RESPONSE
The impulses, or sympathetic (dilation) or parasympathetic (contraction) response signals, travel over separate pathways.



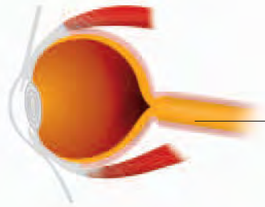
B VOLUNTARY RESPONSE
The sensory impulses that activate voluntary responses occur in various areas of the brain. The nerve path is complex.



C REFLEXES
Some are processed in the brain, but most of them are processed in the spinal cord, where the impulse is processed and the reply is sent.

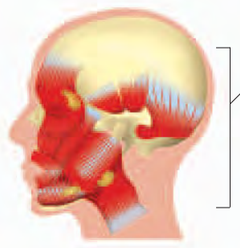
Cranial Nerves

The 12 pairs of cranial nerves extend from the lower part of the brain, as can be seen in the main illustration. Except for the vagus nerve, the cranial nerves control the muscles of the head in the neck region or bring nerve impulses from sense organs, such as the eyes, to the brain. In the case of nerve impulses that come from the eyes, it is the pair of optical nerves that record the sensations from the retina of the eye. The olfactory nerve works the same way for the nose.

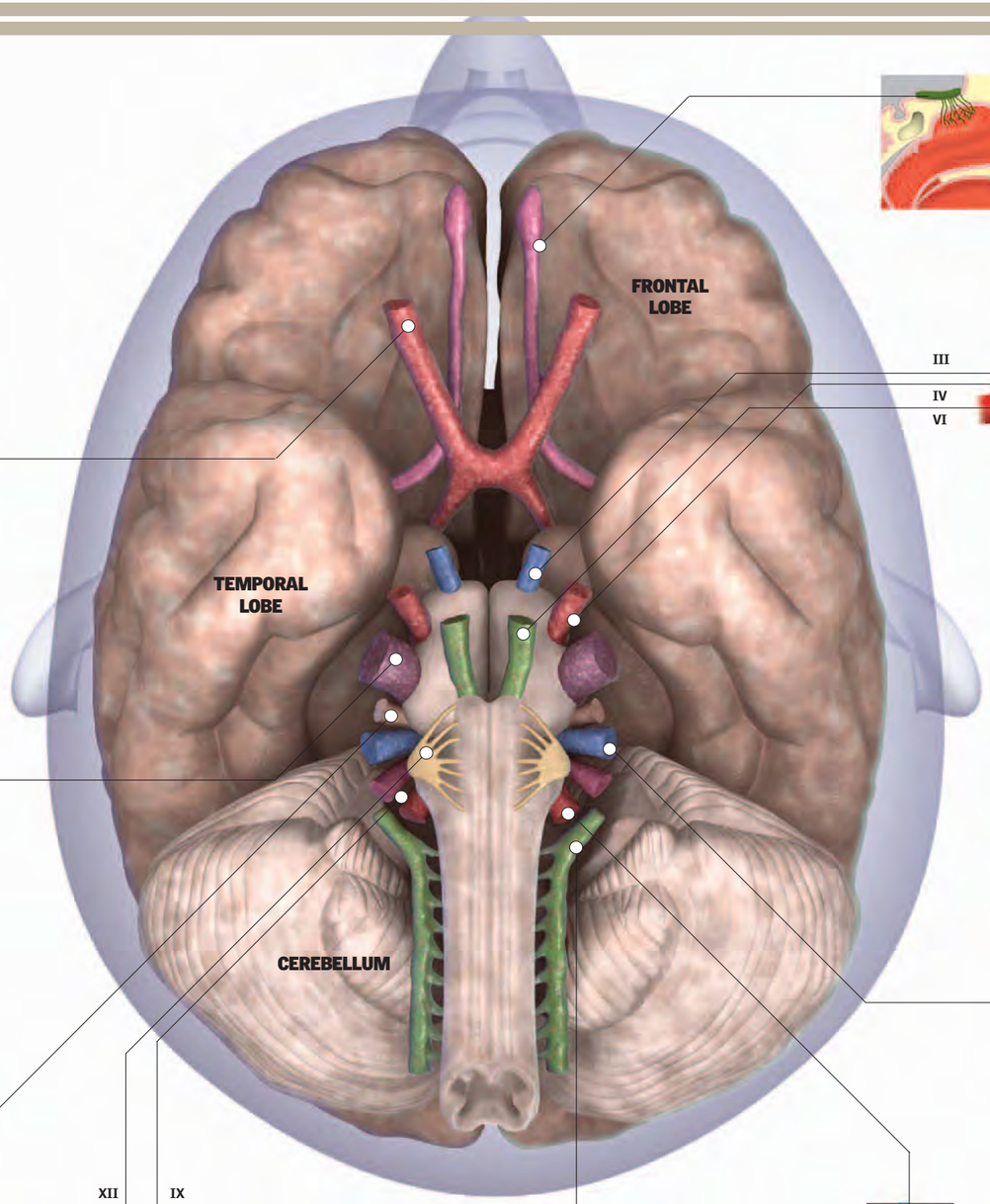


PAIR II
Optic nerve. Supplies the retina. Transmits signals, from the photo receptors, perceived as vision.

PAIR V
Trigeminal nerve. Controls the muscles involved in chewing and transmits sensory information from the eyes, the teeth, and the side of the face.



PAIR VII
Facial nerve. Controls the muscles of facial expressions and the salivary and tear glands. Transmits sensory information from the taste buds.



PAIR I
Olfactory nerve. Innervates the internal and upper region of the nose and transmits signals from the olfactory cells that are perceived as the sense of smell.

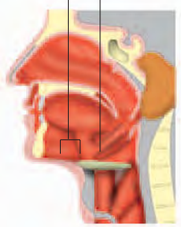
PAIR III
Oculomotor nerve. Controls the movements of the eye and the eyelid. It changes the shape of the pupil and the lens.

PAIR IV
Trochlear nerve. Controls the oblique muscle above the eye.

PAIR VI
Abducens nerve. The nerve that moves the external lateral rectus muscle of the eye.

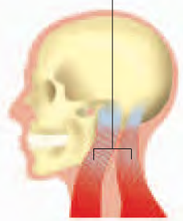
PAIR VIII
The cochlear vestibular nerve. Transmits sensory signals from the inner ear, which are perceived as sound; enables equilibrium.

XII IX

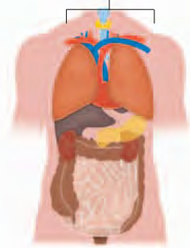


PAIR IX
Glossopharyngeal nerve. Controls the salivary glands and transmits sensory signals from the tongue and the pharynx.

PAIR XII
Hypoglossal nerve. Controls the movements of the tongue.



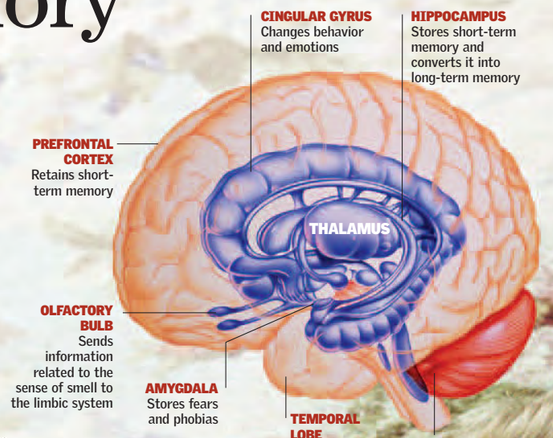
PAIR XI
Accessory nerve. Its function is to control the muscles involved in swallowing and moving the head.



PAIR X
Vagus nerve. Also called the 10th cranial nerve. Among its other functions, it controls the muscles and glands of various internal organs, such as the heart, the lungs, and the stomach.

Dream and Memory

To be able to process the information gathered during the day, the brain takes advantage of periodic dream states. During a dream the brain reduces its activities, and its patterns of thought are disconnected from the external world. The passage from consciousness to dreaming (and from dreaming to consciousness) is the task of neurotransmitters, chemical substances that are manufactured and released from the reticular activator system, a regulator in the cephalic talus, which lies in the brain stem.

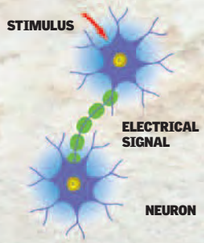


Limbic System

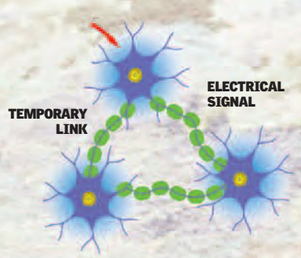
Consists of a complex of structures that wrap around the upper part of the brain stem. These structures control emotions such as annoyance and happiness. They protect us from danger and play an important role in memory formation. For example, the amygdala produces fear when processing danger. The hippocampus permits us to store and remember short-term memories that are brought to the cortex. When the hippocampus is damaged, new memories cannot be incorporated.

Formation of Memory

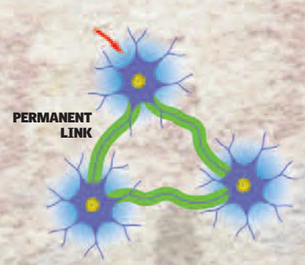
Memory is a set of processes in which unconscious associations are capable of retaining and recording highly varied information. This information can be perceived consciously or unconsciously and ranges from ideas and concepts to sensations that were previously experienced or processed. Memory has many forms, but the two basic ones are the long-term and short-term memory.



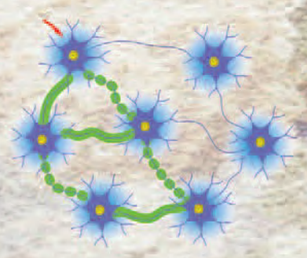
1 CONNECTION. An experience triggers a pattern (or model to be repeated), exciting two neutrons. To form long-term memory the template that was generated earlier by the short-term memory must be replicated. When a stimulus is received, the neuron reacts, sending an impulse to a neighboring neuron.



2 LINK FORMATION. The nerve impulses sent to the neighboring neurons generate a greater capacity for response from the cells that sent the impulses. A temporary union is formed among the cells. In the future, they will be more likely to trigger a nerve impulse together. A neuronal template is beginning to be created.



3 DEEPER LINKS. Every time an event is remembered, a nerve impulse is triggered. As a recollection is repeated, the neurons become more solidly connected. Then the neurons begin to send joint impulses, no matter which was excited first. The development of connections is strengthened with repetition or notable or stressful events.



4 EXPANDING NETWORK. With successive repetition, different groups of neurons begin to form a neuronal network that represents the long-term memory. The more complex the network, the more accessible and durable the memory will be. Each group of neuronal cells represents a different aspect through which one accesses the complete memory.

20 seconds

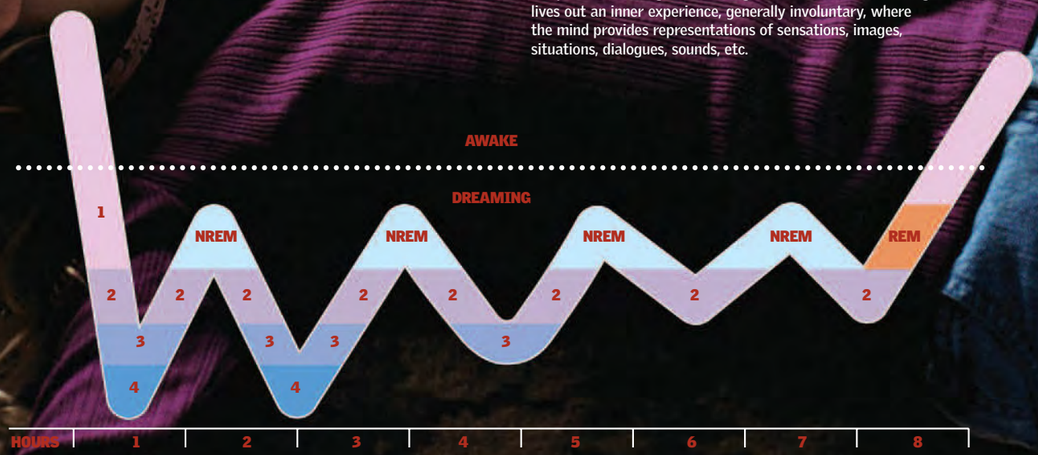
THE TIME AFTER WHICH SHORT-TERM MEMORY LOSES INFORMATION (SUCH AS A TELEPHONE NUMBER) THAT HAS NOT BEEN USED

REM

The acronym for Rapid Eye Movement. The eyes move, though the body is stationary.

Dream Patterns

A pattern is a model that serves as a template, or mold, to obtain the same format. During sleep the two great patterns are REM and NREM, with their four phases. REM sleep is the most enigmatic; it is thought that dreams are produced during REM. During that time the human being lives out an inner experience, generally involuntary, where the mind provides representations of sensations, images, situations, dialogues, sounds, etc.



PHASE 1
Transition between waking and sleeping. The electroencephalograph (EEG), a device that measures cerebral activity, registers alpha waves. The body is relaxed, but if someone disturbs the sleeping person then he or she will wake up.

PHASE 2
Second-phase NREM. The EEG pattern is more irregular. Waking up the person is more difficult.

PHASE 3
Delta waves appear. The vital signs decrease: respiration and the heartbeat slow down, and the body temperature falls.

PHASE 4
Now the dream phase or phase of deep sleep occurs. The delta waves are dominant, and the vital signs drop to minimal levels.

PHASE REM
Rapid Eye Movement. The vital signs increase. The skeletal muscles become inhibited. Dreams enter the scene.

Glossary

Acid

Substance that, in solution, increases the concentration of hydrogen ions and combines with bases to form salts.

Adrenaline

Hormone secreted primarily by the adrenal medulla of the adrenal glands. It constricts blood vessels and is used as a medicine.

Allele

Gene variant that encodes a trait. One diploid cell contains one allele of each parent for each characteristic.

Amino Acid

Organic chemical whose molecular composition includes an amino group (derived from ammonia) and a carboxyl group (a radical that characterizes organic acids).

Antigen

Substance that causes an immune response, such as the production of antibodies, when introduced into the body.

Aorta

Largest artery in the body, originating in the left ventricle of the heart. Down to the diaphragm it is called the thoracic aorta and then the abdominal or ventral aorta to the point where it branches.

Aortic Arch

Curve in the aortic artery near its origin at the heart. The arch has the shape of a shepherd's crook.

Apparatus

Complex of organs that fulfills one function. In the physiology of the human body it is also used as a synonym for system. For example, the digestive apparatus, reproductive apparatus, or respiratory apparatus.

Artery

Blood vessel that brings blood from the heart to the entire body.

Arthroscopy

Surgical procedure used by orthopedic surgeons to inspect, diagnose, and treat problems in the joints. It consists of making a small incision and inserting an arthroscope, an instrument the size of a pencil that contains a small lens and a lighting system to magnify and illuminate the interior. The light is transmitted via fiber optics to the end of the arthroscope, and the interior of the joint can be observed via a miniature television camera.

Articulation

Joint between two bones of the body.

ATP

Adenosine triphosphate. A molecule produced primarily by mitochondria that functions as the primary energy source for the cells.

Atrium

The name for each of the two chambers of the heart that receive blood from the veins.

Basal Metabolism

Activity level of the body functions during rest or while fasting.

Bones

Rigid structures, rich in calcium, that make up the skeleton.

Carpal

The structure of the wrist, composed of eight connected bones arranged in two rows. On the side toward the arm it joins with the cubital and radial bones, and on the side toward the hand it joins with the metacarpal bones.

Cartilage

Flexible skeletal tissue consisting of isolated groups of cells within a collagenous matrix.

Celiac Artery

Artery that brings blood from the heart to the stomach and the other organs of the abdomen.

Cellular Membrane

The flexible covering of all living cells, which contains the cytoplasm. It regulates the exchange of water and gases between the cell and its exterior.

Chromatin

Complex substance in the cell nucleus composed of nucleic acid and proteins.

Cilium

Tiny hairlike protuberance on a cell with a locomotive function in a liquid medium.

Coagulation

Organic process in which the blood turns from a liquid to a solid state and whose normal purpose is to stop bleeding.

Coccyx

Bone formed by the fusion of the last vertebrae. At its base it articulates with the sacral bone. In human beings and other vertebrates that do not have a tail, it is an actual bone.

Coronal

A name given to the frontal bone, located at the anterior and superior part of the cranium. At birth the frontal bone or coronal is divided into two halves, which fuse over time. In medicine this can also refer to a suture that joins the frontal bone with the two parietal bones.

Coronary Arteries

A pair of arteries, originating in the aortic artery, that branch out and supply blood to the heart.

Cortex

The gray material present in most areas of the brain. It is the largest part of the central nervous system. The majority of the most advanced functions occur in the cortex.

Corticoids

Hormonal steroids produced by the adrenal gland cortex. Corticoids can be produced artificially. They have a therapeutic application as anti-inflammatory drugs.

Cystoscope

Apparatus used to explore the inner surface of the bladder.

Cytoplasm

A compartment of eukaryotic cells, bounded by a cellular membrane and the membranes of the cell's organelles.

Diaphragm

Respiratory muscle between the thorax and the abdomen.

Digestion

The set of processes through which the digestive system converts food into substances that can be assimilated by the organism.

Diploid

A cell with two complete sets of chromosomes. It is denoted by the symbol 2n.

Dislocation

The displacement of any bone from its normal position in a joint.

DNA

Deoxyribonucleic acid. A double helix molecule containing encoded genetic information.

Ejaculation

The action of expelling semen.

Embryo

The result of the fertilization of an ovum by a sperm cell. It can develop to become a mature organism.

Emulgent Arteries

Arteries that bring blood from the heart to the kidneys, also called renal arteries.

Endocardium

Membrane that lines the walls of the heart. It consists of two layers: an exterior, consisting of connective tissue, and an interior, of endothelial tissue.

Endometrium

Mucous membrane covering the inner walls of the uterus.

Endoplasmatic Reticulum

Network of membranes in the cell that are interconnected through the cytoplasm and whose function is the synthesis and assembly of proteins.

Endothelial

Organic tissue that lines wall-like structures within the body, such as those of the pleura or of blood vessels.

Enzyme

Protein that helps regulate the chemical processes within a cell.

Erythropoiesis

The creation of red blood cells, stimulated by the action of a protein called erythropoietin.

Follicle

Inward fold of the epidermis in the form of a sac, which usually surrounds the base of a hair.

Gene

Unit of information of a chromosome; it is a sequence of nucleotides in a DNA molecule that fulfills a specific function.

Gland

Organ that has the function of producing secretions that can be expelled through the skin or mucous membranes (salivary glands or sweat glands, for example) or into the bloodstream (the thyroid, for example).

Haploid

From the Greek *haplous*, meaning single. A haploid cell has a single set of chromosomes, unlike the diploid cells. Gametes are haploid.

Hemostatic

Substance or agent that halts hemorrhaging.

Hippocampus

Part of the brain that governs the memory.

Holocrine

Gland with an exclusively secretory function or whose secretion consists of disintegrated cells of the gland itself, such as the sebaceous glands.

Homeostasis

Complex of self-regulatory phenomena that keep the composition and the properties of the body's internal environment constant. It is said that homeostasis is reached when the body's internal environment contains the optimum concentrations of gases, nutrients, ions, and water; when

its temperature is optimum; and when the volume of fluids is optimum for the life of the cells.

Hormone

The product of the glandular secretion whose function is to stimulate, inhibit, or regulate the action of other glands, systems, or organs of the body.

Innominate Bones

A pair of bones, one in each hip, which join the sacrum and the coccyx to form the pelvis. They consist of the fusion of the iliac, the ischium, and the pubic bones.

Lobes

Rounded protuberances of organs, such as the liver, the lungs, or the brain.

Lysosome

Protein that can break down the constituent substances of the walls of certain bacteria and is, hence, a potent antibacterial.

Meiosis

Type of cell division in which two successive divisions of the nucleus of a diploid cell create four haploid nuclei. As a result of this mechanism, gametes or spores are produced.

Meristem

Tissue with cells that produce other cells by cellular division.

Metabolism

Complex of chemical reactions that take place continuously within cells to synthesize complex substances from simpler substances or to degrade a substance into simpler substances. An example is the digestive process.

Metacarpal

Middle part of the skeletal structure of the hand, between the wrist (carpal bones) and the phalanges. It consists of five bones, which are the largest bones of the hand.

Metatarsal

Part of the skeletal structure of the foot, between the tarsus (posterior part of the foot) and the phalanges (toes). It consists of five bones and is usually called the sole of the foot.

Micturition

Act of urinating, or expelling urine.

Mitochondria

Organelle that has a double membrane. The final stage of the aerobic respiration process takes place in mitochondria, where ATP is obtained by breaking down sugars and other substances.

Mitosis

Nuclear division in a cell that forms daughter nuclei identical to the parent.

Mucous Membrane

Covering of body cavities that communicate with the exterior (such as the nose). A mucous membrane contains numerous single-celled glands that secrete mucus.

Muscles

Organs composed of fibers capable of contracting.

Myocardium

Muscular part of the heart, between the pericardium and the endocardium.

Nucleic Acid

Molecule that carries genetic information about the cell. There are two types: DNA and RNA.

Nucleus

The part of the cell that contains the DNA with its genetic information.

Organ

Any part of the body that accomplishes a function.

Osmosis

Movement of a liquid through a selectively permeable membrane.

Papillae

Conical protuberances, usually sensory, formed on the skin or mucous membranes (especially the tongue) by the branching of nerves and blood vessels.

Pericardium

Pair of membranes that surround the heart.

Phagocytes

Cells found in blood and tissue. They capture bacteria or any other kind of noxious particles and "phagocytize," or "eat," them, absorbing them into their cytoplasm and later digesting them.

Phalanges

Bones of the fingers and toes. They extend to the metacarpal bones in the hand and the metatarsals in the foot. Starting from the metacarpals and the metatarsals, they are sequentially numbered: first, second, and third phalanges (of each finger or toe). The word "phalanges" commonly designates the first phalanges, or each of the jointed parts of the fingers or toes.

Physiology

Study of the functions of the organism.

Polymer

Macromolecule consisting of repeated structural units, called monomers.

Popliteus

Section of the leg opposed to, or behind, the knee.

Protein

Substance that makes up the cells. It is a biopolymer consisting of one or several chains of amino acids, fundamental for the constitution and functioning of living material, such as enzymes, hormones, and antibodies.

Ranine Artery

Artery that branches out toward the front of the tongue.

Respiration

The act and effect of inhaling air, primarily through the nose, to take in the substances that the body requires, such as oxygen, and after processing them exhaling unneeded substances, such as carbon dioxide.

Ribosome

Organelle located in the cytoplasm that governs the formation of proteins based on information provided by the nucleic acids.

Ribs

Long and curved bones. They originate at the back of the body at the spinal column and curve forward. They are called "true" if they end at the sternum and "false" if they remain floating without completely enclosing the rib cage.

Schwann Cells

Cells that produce myelin, a fatty insulating substance that prevents electrical signals from losing strength as they move away from the body of the neuron.

Semen

The spermatozoa and fluids produced in the male genital organs. It is often called sperm.

Sensation

Physiological process of receiving and recognizing stimuli produced by vision, hearing, smell, taste, touch, or the body's spatial orientation.

Sleep

State of repose characterized by inactivity or suspension of the senses and voluntary motion. The cerebral activity called dreaming takes place during sleep.

Spinal

Relating to the spine.

Spinal Bulbar

Part of the cerebral trunk that goes from the annular protuberance to the cranium's occipital foramen.

Spine

The neuroskeletal axis that runs along the medial dorsal of the body and consists of a series of short bones called vertebrae, which are arranged in a column and jointed with each other.

Sternum

Bone of the anterior thorax, which joins the front of the ribs.

Striated Muscle

Muscle used for voluntary motion. Its muscle fibers show striations, or grooves.

Subclavian Arteries

Pair of arteries, one of which branches off from the brachiocephalic trunk (on the right side of the body) and the other from the aortic arc (on the left). They run toward the shoulder on each side and, after passing below the clavicle, become the axillary artery.

System

Complex of organs that participates in any of the principal functions of the body. A synonym of "apparatus."

Tarsal

The skeletal structure of the leg between the foot and the metatarsal. It consists of seven bones that constitute the posterior part of the foot.

Tissue

Group of identical cells that together accomplish a function.

Uterus

Hollow viscera of the female reproductive system. It is located inside a woman's pelvis. In the uterus, or womb, either menstrual fluid is produced or a fetus develops until it is born.

Veins

Blood vessels that bring blood from the entire body toward the heart.

Ventricles

Cavities of the heart that receive blood from their respective atrium (right or left) and pump it through the arteries.

Viscera

Organs located in the principal cavities of the body (such as the stomach or the liver within the abdominal cavity).

Vitamins

Organic substances present in food. The body ingests them to ensure the balance of various vital functions. There are different kinds of vitamins, designated with the letters A, B, C, etc.

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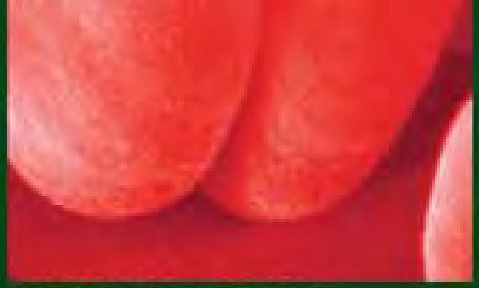

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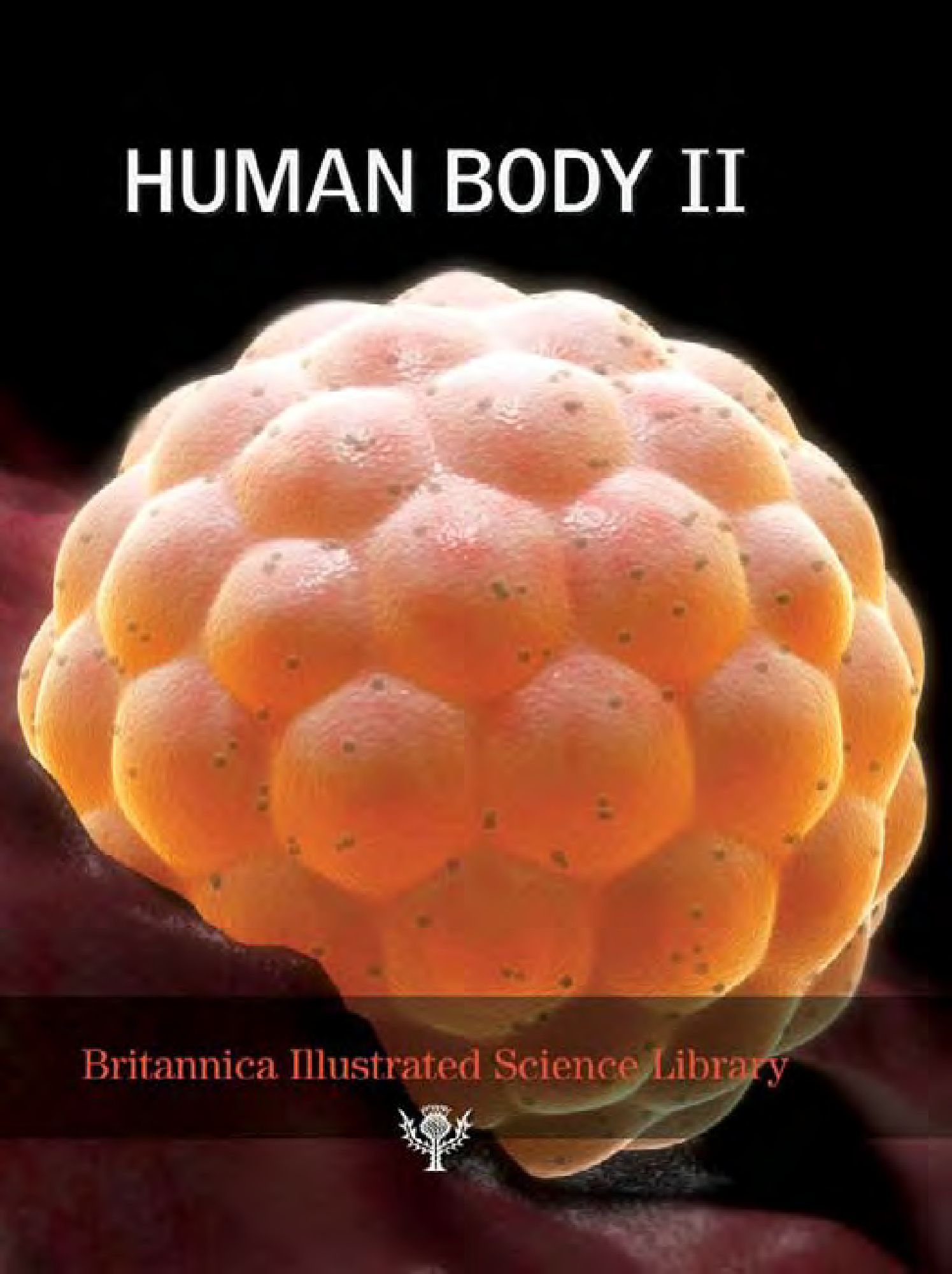

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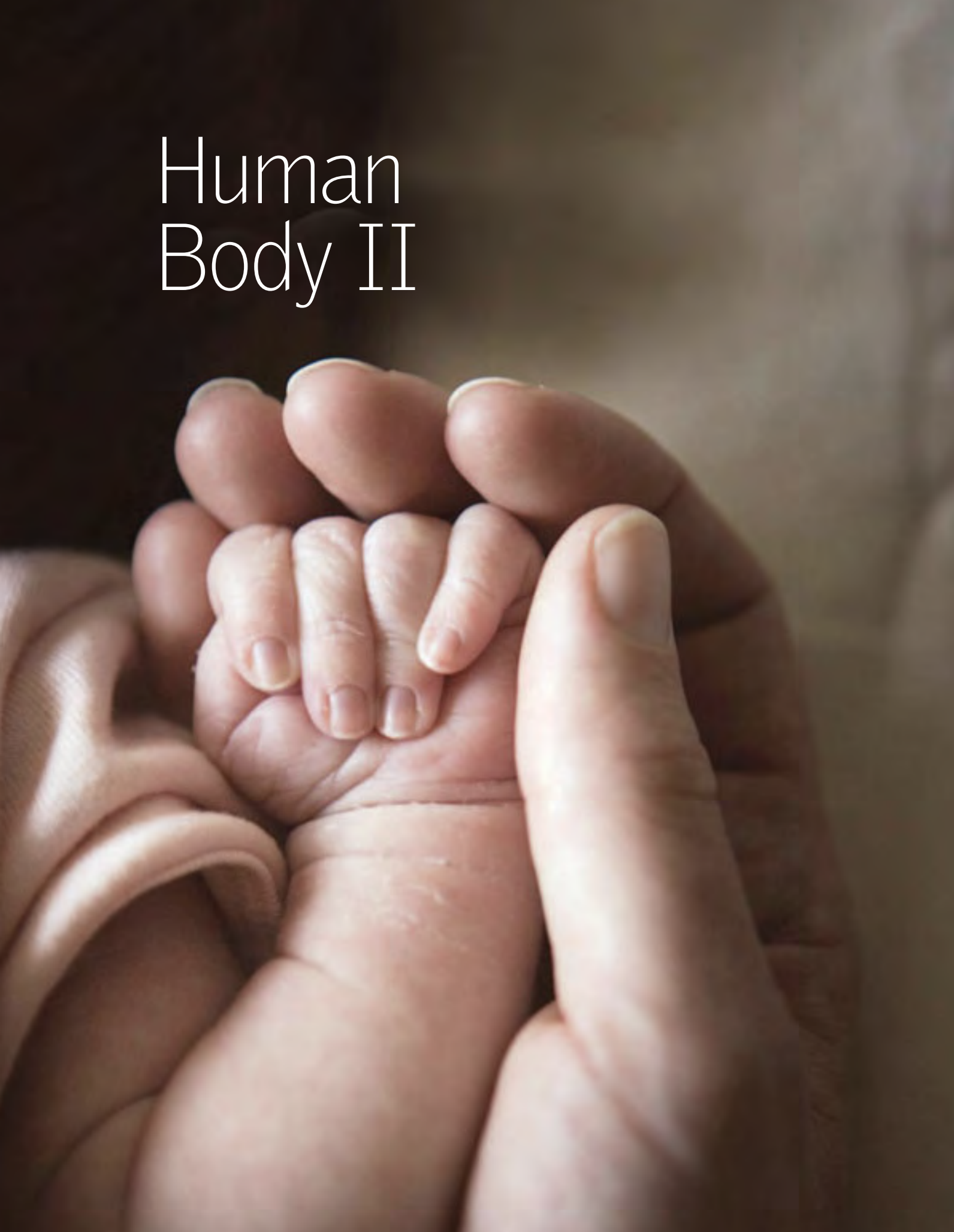

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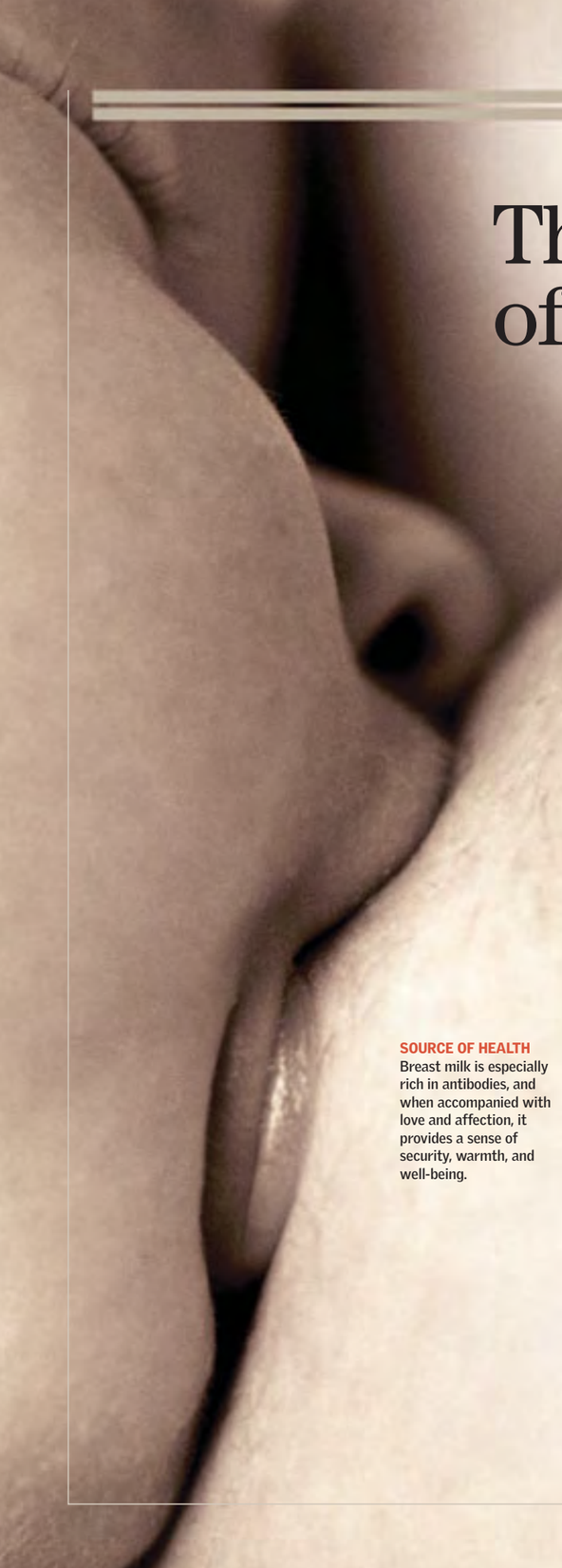


SOURCE OF HEALTH
Breast milk is especially rich in antibodies, and when accompanied with love and affection, it provides a sense of security, warmth, and well-being.

This is a moving book. A guide for parents as well as young people, it recounts in detail the almost magical way in which babies evolve from the very moment that fertilization occurs. Thanks to new technological advances, today it is possible to visualize and re-create images of what happens inside a woman's body when a sperm travels through the uterus and the gelatinous membrane that surrounds the egg. Incredible photos show, day by day, how the embryo evolves, when the heart begins to beat, and even when the brain, eyes, legs, arms, mouth, and teeth are formed. This book contains a wealth of information, with photographic details that show you the inside of the body from a totally new viewpoint.

The book is divided into five chapters. The first two are dedicated to the formation and development of the baby, and the rest deal with everything that happens to the body when it gets sick—from how the HIV/AIDS virus affects us to what happens when arteries become blocked because of fat deposits. The information, reviewed by professionals and accompanied by incredible illustrations, will captivate you from the first page. The last chapter is devoted to tracing the landscape of future medicine. The surprising advances in molecular biology and genetics allow us to have new therapeutic and diagnostic tools that make it possible to think that, in the future, humans will live eternally. The themes covered and shown here have a scientific basis. We tell you, for example, which mechanisms regulate the operation of the genes and how these mechanisms can correct certain errors in the DNA—the starting point for many illnesses of genetic origin, including many forms of cancer. In a not too distant future, nanomachines (many times smaller than a cell) could be guided inside the body to eliminate obstructions in blood vessels or to kill cancer cells. With particles the size of amino acids, sick cells could be eliminated without damaging the healthy ones. Like guided missiles, the molecules would go directly to the damaged cells. This type of therapy has already been demonstrated in mice and rats, and, although the tests are still in development, it is expected that within the next few years this type of revolutionary treatment, which combines genetics with pharmacology, could be applied. Currently there are patients on whom certain drugs have toxic effects or do not have the desired effect; in the future, drugs could be made according to the genetic makeup of each patient.

Another aspect to highlight in the use of new technologies is related to health informatics, or medical informatics, in which all kinds of patient information is managed. Such a system already allows all hospitals in some cities, such as Vienna, Austria, to communicate digitally. That way a doctor can quickly access the medical record of the person through a remote communication network such as the Internet. It is not strange to imagine that in coming years everyone will carry their medical records on a keychain that, when connected to a computer, would provide all their medical information. There is real evidence that in the next decades the way that medicine will treat diseases requiring the replacement of organs or tissues will also change. The tissue created in the laboratory will be genetically identical to the patient's, so there will be no rejection. Once this is achieved, transplants and artificial organ implants will be a thing of the past. Today in the cases of heart failure, when the treatments do not work, a transplant is sought. In a few more years, this will be unnecessary. Ventricular assistance devices, combined with stem-cell implants, will be used to allow regeneration of the damaged muscle.

In addition, the health of many people will be determined during fetal development. As a result of the advances in prenatal diagnostic methods, the possibility has appeared in recent years of carrying out surgical procedures to correct certain congenital problems inside the womb. It is not difficult to foresee the development of medical units in which the fetus is a patient. Even though many of these advances are still in the research stage, it is not unrealistic to believe that they will end up being useful. Several decades ago, nobody would have thought about replacing sick organs with healthy ones or the possibility of choosing a baby's sex. So why not fantasize about virtual medicine that is safer, simpler, and more effective or even about the possibility of living forever? ●

From Zygote to Embryo

FERTILIZED EGG
After fertilization, the egg implants itself in the endometrium and begins to develop.

THE ORIGIN OF SEX AND LIFE 8-9
FERTILIZATION OF THE EGG 10-13
FIRST HUMAN FORMS 14-21

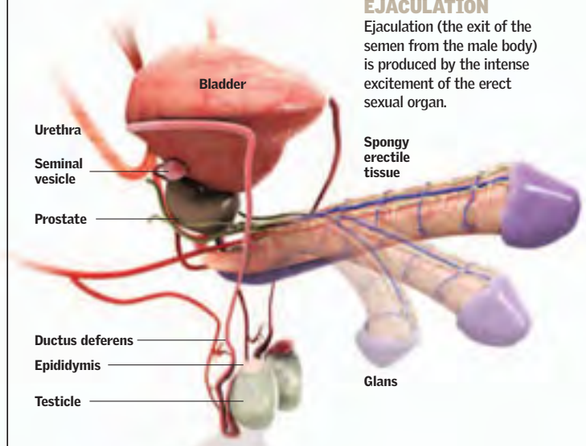
From conception until the third month of pregnancy, what takes place inside the mother's belly? Day by day, during the phases of mitosis, what happens at this embryonic stage, the most critical one during pregnancy? What changes does the embryo go through? Here we present incredible images that show the embryo from its formation to the moment it implants itself in the endometrium and measures about 0.2 inch (5 mm). At what time do the heartbeats begin and the eyes, mouth, and legs begin to form? Also, what is the role of the placenta, the organ that gives the unborn baby the different nutrients and oxygen it needs to continue developing? Turn the page. ●

The Origin of Sex and Life

The origin of human reproduction is sexual. Men and women can have sex any time during the year, unlike most other species, which have their specific times of heat. The ability to have sex begins at puberty, the age when the sexual organs develop. Women are fertile from their first menstrual period until menopause at around age 45. Although their sexual activity continues after this age, they no longer produce eggs, the female sexual gametes capable of being fertilized by sperm.

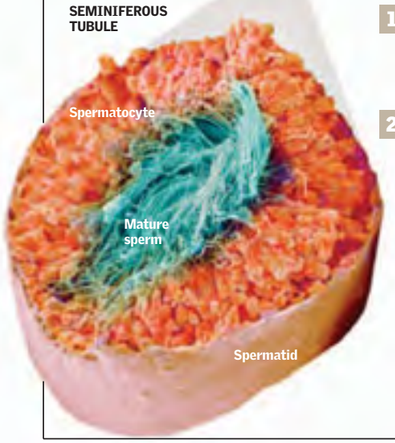
The Male Sexual Apparatus

The testicles, or male sexual glands, lie below the pelvis within a structure called the scrotum. It is there that sperm—the mobile sex cells—are produced. During sexual intercourse, these cells, if they reach the female vaginal canal, head toward the egg so that one of them may fertilize it. The ductus deferens is the path through which the sperm travels to be joined by materials from the seminal vesicles and the prostate. This combination makes up the semen, which, in the moments of maximum sexual excitation, will move to the urethra to exit the man's body through the penis.



EJACULATION

Ejaculation (the exit of the semen from the male body) is produced by the intense excitement of the erect sexual organ.



1 FROM REST TO AN ERECTION
A physical or mental stimulus causes the cavernous bodies to fill with blood and the penis to swell.

2 EJACULATION
If the penis continues being stimulated, the seminal vesicle contracts and expels the semen.

SPERM PRODUCTION

Sperm originates inside the 10,000 seminiferous tubules at a rate of 120 million a day and are stored in the epididymis. This process requires a temperature of 93° F (34° C), which the testicles achieve by being outside the abdomen.

Gametes and Hormones

Testicles and ovaries are glands that produce the sex cells, or gametes—sperm and eggs, respectively. Gametes are haploid cells. In other words, they possess half the chromosomes of any other human tissue cell, which contains a total of 46. Upon uniting at conception, each gamete contributes half of the genetic load of the new embryo. The sex glands also produce hormones that determine secondary characteristics and, in women, ovulation.

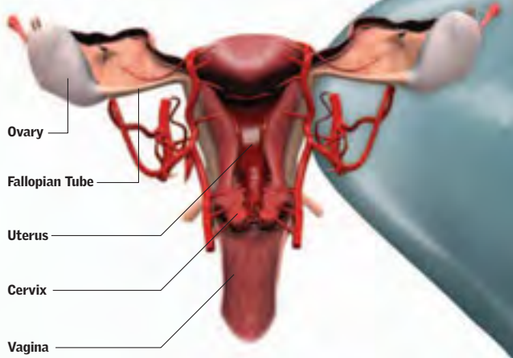
FALLOPIAN TUBE
A tube 4 to 5 inches (10-12 cm) in length and about 0.1 inch (3 mm) in diameter, with internal cilia that propel the egg toward the uterus.

FIMBRIAE
form a tunnel through which the mature egg is introduced into the fallopian tubes.

28
DAYS A TYPICAL MENSTRUAL CYCLE LASTS

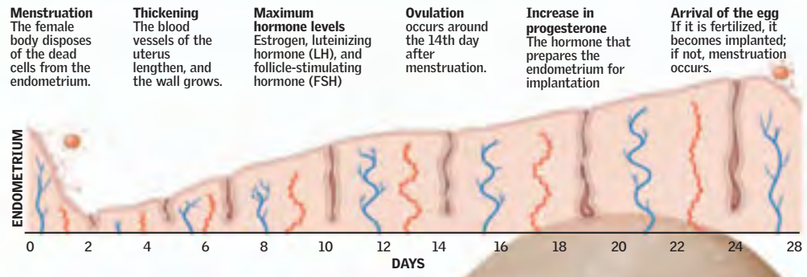
OVARY
contains many follicles with immature eggs and releases hormones responsible for the menstrual cycle and female sexual activity.

FRONT VIEW



The Menstrual Cycle

The uterus is prepared for the implantation of the fertilized egg. For this, the woman's hormones have stimulated the uterus to thicken its internal wall (endometrium). If no egg is implanted, the thickened wall breaks down and the waste material is disposed of outside the body, together with the unfertilized egg. This process is synchronized with ovulation and is repeated regularly throughout the woman's fertile life, from puberty until menopause.



The Sexual Organs of the Woman

With the exception of the vulva, which is external, the female sexual apparatus (which allows a woman to have an active sexual life, become pregnant, and give birth) lies completely inside the abdominal cavity, where it is supported and protected by the pelvis. Its basic shape is that of a cavity formed by the vagina and the uterus. The ovaries produce the eggs, or sex cells, and hormones. Periodically a mature egg leaves the ovary and installs itself in the uterus (ovulation). There, if it has not been fertilized in the fallopian tube, the body will expel it naturally together with the residues of the endometrium (menstruation).

UTERUS
A pear-shaped cavity with thick, muscular walls. Its internal wall is the endometrium.

BLADDER

VAGINA
Cavity that is anatomically prepared to receive the penis during sexual intercourse

OVULATION CYCLE

Inside the ovary there are thousands of immature eggs, each one wrapped in a follicle, or sac. In each cycle, a mature egg is sent to the uterus.

1 The egg begins to grow in a follicle, stimulated by FSH.

2 Protection
The follicular cells form an envelope around the egg.

3 Maturing of the egg
The egg bulges from the ovarian walls, and hormonal secretions increase.

4 Maximum size
The follicle has formed a fluid-filled cavity.

5 Ovulation
Halfway through the cycle, the follicle bursts and releases a mature egg.

6 Formation of the corpus luteum
The ruptured follicle closes and releases progesterone.

7 Degeneration of the corpus luteum
occurs only if the egg has not been fertilized.

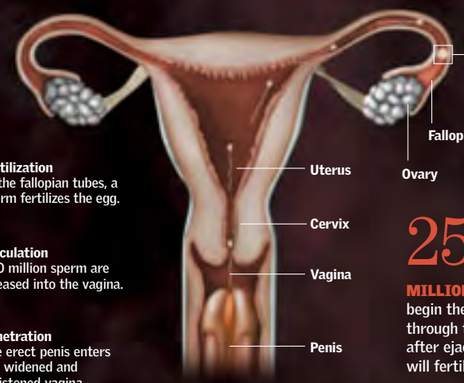
Fertilization of the Egg

Fertilization is the starting point for the development of pregnancy. After intercourse, two sex cells, or gametes, fuse together, giving rise to an ovum, or zygote, where the chromosomes of the two gametes are united. In humans, these sex cells are the sperm and the egg. For conception of a new life, a sperm must fertilize the egg in a tough competition with hundreds of millions of other sperm.

The Journey of a Sperm

After ejaculation, millions of sperm begin their journey through the genital tract. Only 200 will reach the egg. The trip toward the fallopian tubes takes anywhere from 15 minutes to several hours. To reach them, sperm use their tails, and they are helped by contractions in the walls of the vagina and the uterus. Inside the egg, the sperm loses its tail and midsection, which dissolve. The head, which contains the genetic material, moves toward the plasma membrane of the egg. The march toward fertilization is underway.

FROM PENETRATION TO FERTILIZATION



3 Fertilization
In the fallopian tubes, a sperm fertilizes the egg.

2 Ejaculation
250 million sperm are released into the vagina.

1 Penetration
The erect penis enters the widened and moistened vagina.

250
MILLION SPERM
begin their journey through the genital tract after ejaculation. Only one will fertilize the egg.

The Sperm

The male sex cell. With a tail, a head, and a midsection, millions of sperm fight to fertilize the egg, a mission that only one of them will accomplish. It measures 0.002 inch (0.05 mm) in length.

MIDSECTION
contains mitochondria that release energy to move the tail.

HEAD
contains the genetic information (DNA).

TAIL
helps the sperm move through the external membranes of the egg.

1 In the Race

Hundreds of millions of sperm go in search of the egg immediately after ejaculation during reproduction.

ZONA PELLUCIDA
Thick, translucent layer outside the cell membrane. It is penetrated by the sperm.

CELL MEMBRANE
protects the egg. The sperm goes through it after passing through the zona pellucida.

2 Only One Winner

The sperm that will finally fertilize the egg will release enzymes that allow it to cross through the external membranes of the egg. When it enters, it loses its tail and midsection. What remains in the egg is the head with the genetic material.

3 Fertilization

A zygote, or ovum, is produced from the union of the egg and the sperm. The cell will begin its cell division through mitosis.

NUCLEUS OF THE EGG
contains the genetic material made up of DNA.

The Egg

When the egg is fertilized by a sperm, pregnancy starts. Fertilization occurs in the exterior portion of the fallopian tube where the sperm meets and joins with the egg. Two days after fertilization, the egg travels toward the uterus, pushed along by the muscular action of the fallopian tube. The egg, once fertilized, thickens its outer surface to prevent the entrance of any new sperm. After fertilization, the zygote begins to divide through mitosis.

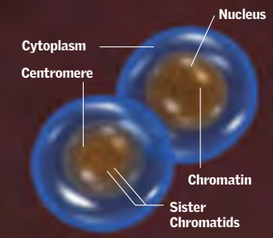
Day 1

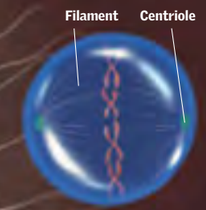
4 Mitosis

The process of generating new cells. Cell division begins with the replication of the DNA. In this way, a "mother" cell generates two identical "daughter" cells that contain the same genetic information as the mother cell. The process of replication for cell division occurs for each of the 46 chromosomes in each cell. The cells of the embryo divide through mitosis, just like most adult tissue cells.

PHASES OF MITOSIS

1 Prophase
The DNA of the chromosomes has already been copied. Two identical strands are formed, joined at the center by a structure called a centromere.





2 Metaphase
The membrane that covers the cell nucleus disappears, and filaments form in the cell. The chromosomes align themselves along these filaments across the middle of the cell.

3 Anaphase
The filaments "tug" the duplicated chromosomes. The duplicated individual chromosomes move toward the two ends of the cell.

4 Telophase
The filaments disappear, and a new nuclear envelope forms around each group of 46 chromosomes. The nucleus has divided in two.

5 Late telophase
The new cells have been formed. The daughter cells contain the same genetic material as the original cell.

0.1 inch (3 mm)
DISTANCE SPERM TRAVELS IN A MINUTE

Zona pellucida

A membrane of glycoproteins that surrounds the plasma membrane of an oocyte, a female sex cell. This structure attracts the sperm and is vital for the release of the sperm head. In humans, the membrane degenerates and breaks down five days after fertilization.

Day
2

Zygote

The resultant cell from the union of the male gamete (sperm) with the female gamete (egg) in sexual reproduction is called the zygote. Its cytoplasm and organelles are from the maternal egg. It contains all the necessary genetic material for fetal development.

0.004 inch (0.1 mm)

DIAMETER OF THE ZYGOTE

Fertilization

Fertilization occurs in the upper part of the fallopian tube. When the head of the sperm penetrates a mature egg, the nuclei of both sex cells, each one with 23 chromosomes, fuse to form the zygote, or ovum. With 46 chromosomes, the zygote will begin the process of successive cell divisions through mitosis. It will begin the journey from the fallopian tubes toward the endometrium, where it will implant itself.

12 hours

How long it takes the zygote, or ovum, to divide through mitosis. Compact masses are successively formed in these cellular multiplications.

The Zygote's Journey

Once the sex cells have formed the zygote, it begins the journey toward the uterus through the fallopian tube. During this journey, several cellular divisions will take place. Before entering the uterine cavity, a mulberry-shaped compact cellular mass is formed (the morula). Within the uterus, cellular divisions take place every 12 hours until the blastocyst stage (about 64 cells) has been reached. Once on the uterine lining, the blastocyst adheres to it, and shortly thereafter implantation takes place. From that moment, embryonic growth begins.

Formation of the Morula

The zygote goes through three stages of cell division. While it travels through the fallopian tube, it divides first into two and then into four identical cells. After 72 hours, it will have reached the stage of 16 cells, at which point a mulberry-shaped cell agglomerate called the morula is formed (the name comes from the Latin word morum, meaning "mulberry"). The morula continues its journey through the fallopian tube until it reaches the uterus. Cell division continues until a more solid ball with 64 cells, the blastocyst, is formed. Once the blastocyst attaches itself to the interior of the uterus, the formation of the embryo begins.

X-ray of the morula

The morula is made up of 16 cells in its initial state. As it divides, it will reach 64 cells, at which time it becomes a blastocyst.

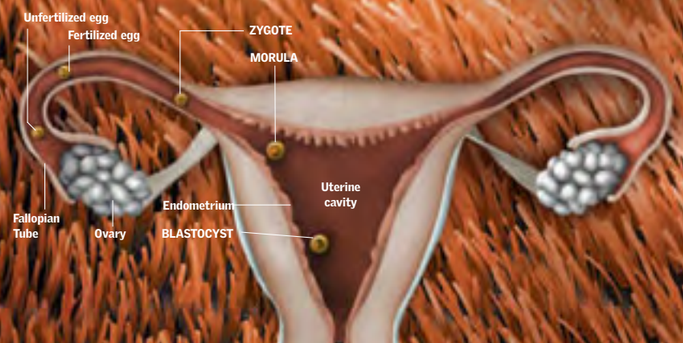
BLASTOMERES
Small cells that make up the body of the morula

MEMBRANE
covers the cellular mass; made up of proteins.

LIQUID
Fluid develops within the intercellular spaces.

Morula

The second important stage of development prior to the formation of the blastocyst. It forms from the repeated mitosis of the zygote. Initially its interior contains 16 blastomeres, which are the first cells that develop from the zygote. Inside the morula, these cells are uniform in shape, size, and physiological potential.



9 days

AFTER FERTILIZATION
The blastocyst, the stage prior to the embryonic stage, implants itself in the uterine wall.

Implantation

After cellular division to 64 cells, the morula becomes a blastocyst, a more compact and solid mass. Once formed, the blastocyst moves freely in the uterine cavity for 48 hours before finding a place to implant itself in the endometrium. The endometrium relaxes to ease implantation of the blastocyst. Nine days after fertilization, the embryo will already be in the uterine wall. After implantation, the embryo begins to grow. If the woman has very low levels of estrogen and progesterone, the endometrium can rupture and cause implantation to occur in the wrong place.

Day
4

Blastocyst

The last step before growth of the embryo. The cellular mass is covered with an external layer called the trophoblast. The trophoblast releases enzymes that help the blastocyst adhere to the endometrium.

TROPHOBLAST
forms the embryonic part of the placenta.

CAVITY, OR BLASTOCOEL
contains liquid that passes through the zona pellucida from the uterine cavity.

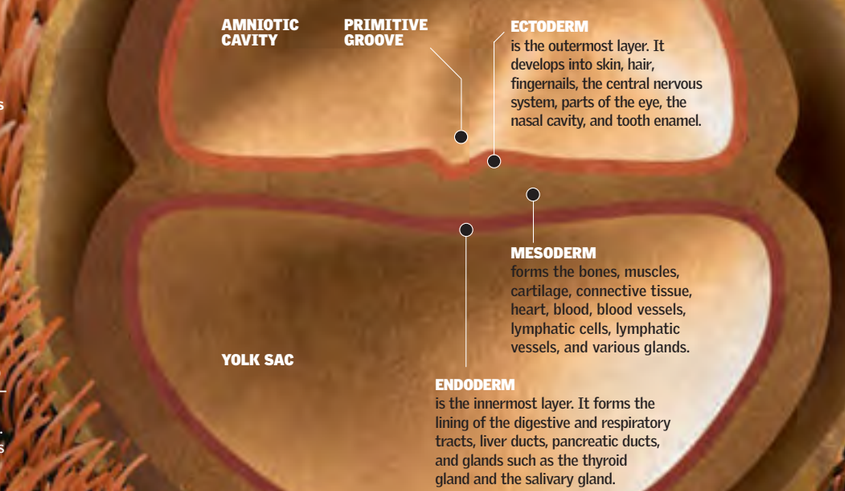
MASS OF CELLS
They make up the embryo, or embryoblast.

IT IMPLANTS NINE DAYS AFTER FERTILIZATION.

Day
9

Trilaminar disk

begins to form from the embryonic bilaminar disk and is complete by day 15. From the trilaminar disk, three germinative layers will develop; they will give rise to the distinct parts of the body: mesoderm, endoderm, and ectoderm.



The Endometrium

The inner layer of the uterine wall, it is made up of the myometrium—the external musculature—and the endometrium—the internal mucosa. Its function is to receive the ovum for implantation. When there is no pregnancy, the endometrium is the bloody tissue lost during menstruation.

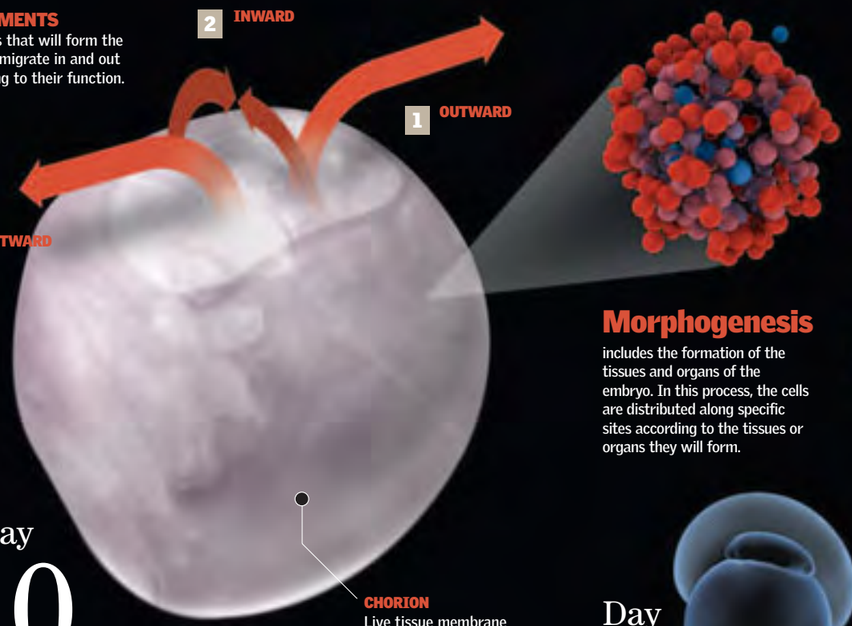
First Human Forms

Nine days after fertilization, the blastocyst has installed itself in the wall of the uterine endometrium, where it will spend the rest of the nine months of gestation before being born. The blastocyst measures slightly more than 0.004 inch (0.1 mm), and the uterine wall increases in size and attains a spongy consistency, the product of an intense supply of hormones by the ovaries. The uterine wall is where the stages of embryonic development will continue. The formation of the various kinds of tissues begins, and in the third week, the heartbeat starts.

Protective Membrane

The rubbing of the blastocyst against the zona pellucida of the endometrium (normally in the back of the uterus, the part closest to the spine) leads to the release of enzymes that interact with the embryo. The blastocyst has little trouble penetrating the porous wall. At the same time, a new membrane forms: the chorion, which will protect the embryo.

MOVEMENTS
The cells that will form the embryo migrate in and out according to their function.



Day 10

Cellular Differentiation

Inside the embryo are cells that will form the skeleton as well as cells that will make up the viscera. Originally undifferentiated, they begin to move, seeking their place. Some cells will move outward (those that will form the skeleton) and others inward (those that will make up the viscera). The latest research has shown that some cells release certain chemicals that provoke other cells to do certain tasks. These substances are called morphogens.

1 First, the cells related to skeleton formation migrate toward the outside. They place themselves on the wall of the embryo.

2 Soon after, the cells related to visceral growth begin to migrate toward the inside. The embryonic disk undergoes a transformation.

Morphogenesis

includes the formation of the tissues and organs of the embryo. In this process, the cells are distributed along specific sites according to the tissues or organs they will form.

Day 13

CHANGES IN SHAPE
When the cells that will form the viscera find their place, the embryo undergoes a transformation within a few hours. From the disklike appearance of day 13, a tube forms from filaments that are generated by these cells.

The Placenta Forms

From the implanted blastocyst, new cellular formations begin to branch out over the chorion. These branches (called trophoblasts) are the source of the placenta, a disk-shaped interchange organ that grows between the chorion and the tissues of the endometrium. In the placenta, the blood vessels of the mother intertwine with those of the embryo without joining. The embryoblast, which contains the source of primitive blood for the development of the liver and the marrow, grows under this disk, which serves as a protective and immunological barrier.

1,000 cells
MAKE UP THE HUMAN EMBRYO BY THE TIME THE PLACENTA IS FORMED (DAY 13) AND GASTRULATION BEGINS.

8 inches (20 cm)
is the average diameter of the placenta responsible for blood circulation between the mother and the fetus at the time of birth.

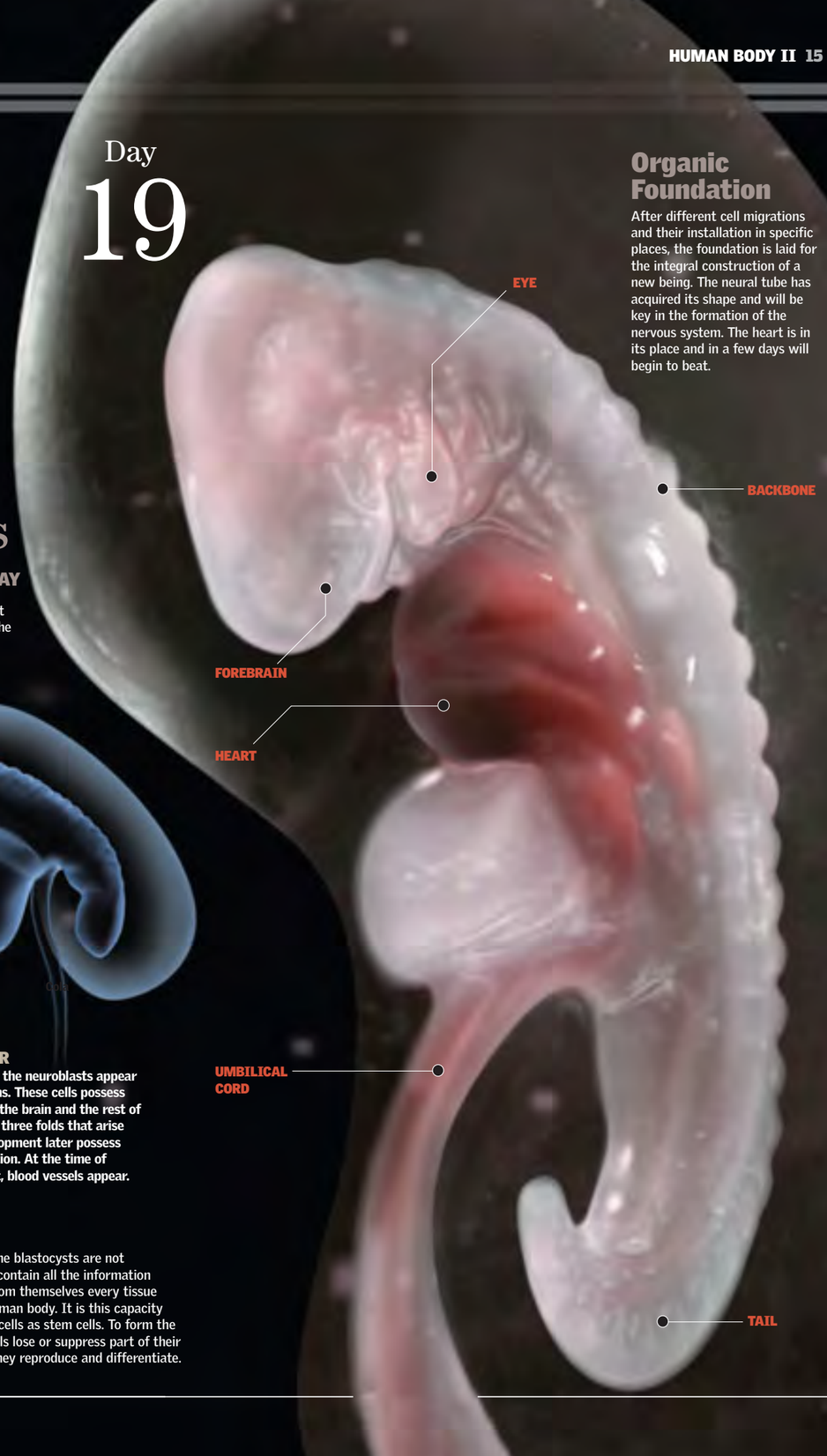
87 gallons (330 L) A DAY
The amount of blood that must circulate through the umbilical cord to sustain embryonic growth.

ORGAN PRECURSOR
Between days 16 and 19, the neuroblasts appear and the neural tube forms. These cells possess information to generate the brain and the rest of the nervous system. The three folds that arise during neural tube development later possess sensory and motor function. At the time of neural tube development, blood vessels appear.

Stem Cells

The cells that make up the blastocysts are not differentiated, and they contain all the information necessary to generate from themselves every tissue that will make up the human body. It is this capacity that distinguishes these cells as stem cells. To form the various tissues, these cells lose or suppress part of their genetic information as they reproduce and differentiate.

Day 19



Organic Foundation

After different cell migrations and their installation in specific places, the foundation is laid for the integral construction of a new being. The neural tube has acquired its shape and will be key in the formation of the nervous system. The heart is in its place and in a few days will begin to beat.

Embryonic Stage

It is still impossible to see a human shape at this moment of intrauterine development. The embryo is smaller than a grain of rice and has at one end a type of curved tail that will disappear as development progresses. In the interior and in the folds of the embryo there are groups of various cells, each one with different instructions according to the organs they must form. In this period, the cells of the cardiovascular system initiate the beating of the heart.

Day
22

LENGTH: 0.2 inch (4 mm)
WEIGHT: 0.001 ounce (0.03 g)

ESOPHAGUS separates from the breathing tube to allow the appropriate development of the digestive system.

LUNGS begin to develop. They are the last organs to acquire their shape and be completely functional.

SPINE has 40 pairs of muscles and 33 pairs of vertebrae. It is the hardest part of the embryo.

CROSS SECTION

AMNIOTIC SAC contains the liquid in which the fetus floats and is made up of two membranes that protect the embryo.

1

2

C-shaped

In most vertebrates, the curved C-shape will disappear as the body slowly grows.

1 FOLD
The embryonic tail acquires a curved shaped before its disappearance.

2 ABSORPTION
The tail is absorbed when the embryo begins the road to fetal development.

Liver and Kidneys

During the embryonic period, the first two months of gestation, the liver is the central organ for blood production. It is in charge of producing blood cells because the bone marrow, the substance that will have this function with the beginning of the fetal period, is not yet complete. In addition, the primitive kidneys begin to appear in the embryo from a protuberance called the mesonephric ridge. The kidneys filter the metabolic waste from the blood so that the embryo receives only the nutrients.

127 million
The average number of cells in the eye when it acquires its definitive shape.

THE EYE WILL BE ABLE TO DISTINGUISH BETWEEN
10 million
COLORS AND SHADES OF LIGHT AND DARK WHEN IT REACHES MAXIMUM DEVELOPMENT.

Formation of the Eye

All vertebrates' eyes develop according to the same process. From certain changes in the ectodermal layer and invagination patterns on the surface of the embryo, the eye develops an "inverted" retina, in which the initial detection of light rays occurs in the outermost portion. In this way, the light-sensitive elements are situated on the outer regions, and the neural connection with the brain is in the inner region. The retina houses in its interior light-sensitive cells that have the function of receiving light and transmitting the correct information to the brain. The final development in the eye's functionality will occur at approximately the seventh month, when the baby will open its eyes for the first time and will react to changes of shade between light and dark.

DEVELOPMENT OF THE EYE

1 DEVELOPMENT OF THE PLACODE
By day 30, the lens placode, a region on the embryonic surface, comes in contact with the optic stalk.

2 FORMATION OF THE VESICLE
A day later, invagination of the lens placode takes place, and the lens vesicle forms.

3 DEVELOPMENT OF THE RETINA
On day 32, the neural retina and the pigment epithelium are formed. The lens vesicle detaches from the placode.

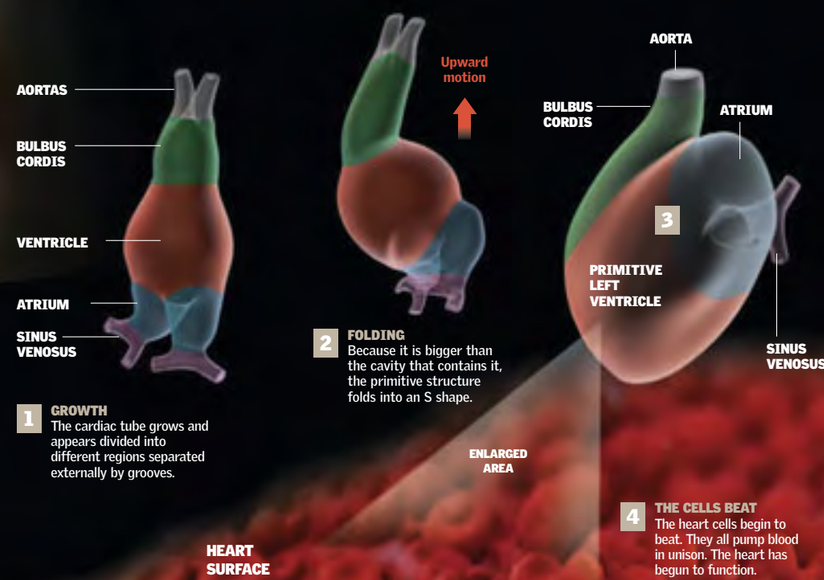
The Heart Begins to Beat

By day 22, the heart is already active, just like the brain. Its division into subregions has begun, and it now makes up, together with the brain, half the size of the fetus. Initially the heart is simply a pump that maintains the flow of blood in the body and toward the placenta. When the four chambers are developed, the heart acquires the ability to gather the blood from the lungs and distribute it toward the organs throughout the body.

Development of the Heart

After the differentiation of the cells that form the blood vessels, the cardiac muscle appears and begins to pump with the beating of its cells.

50%
of the embryo is composed of just two organs: the heart and the brain.



1 GROWTH
The cardiac tube grows and appears divided into different regions separated externally by grooves.

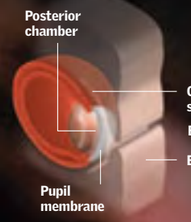
2 FOLDING
Because it is bigger than the cavity that contains it, the primitive structure folds into an S shape.

3 BULBUS CORDIS
Composed of three parts: the arterial trunk, the arterial cone, and the primitive right ventricle

4 THE CELLS BEAT
The heart cells begin to beat. They all pump blood in unison. The heart has begun to function.

Changes in the Head

The brain, the organ of the central nervous system that coordinates all muscle movement, begins to develop. Inside it, the pituitary gland (hypophysis) begins to form. It will produce growth hormone and other hormones. The jaw and the facial muscles also begin to develop.



4 EYE
The eyelid forms. A membrane prepares the final shape of the pupil.

CORD
The umbilical cord begins to develop and, by the time of birth, can measure up to two feet (60 cm) in length.

UPPER LIMB BUD
appears at day 26.

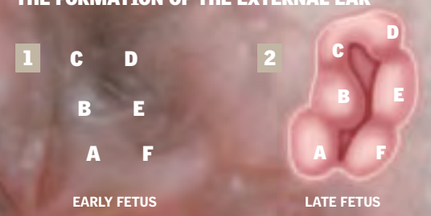
HAND PLATE
appears at day 33.

DIGITAL RAYS
appear at day 40.

TISSUE
Connective tissue forms. It will engender the cells that form the cartilage, bones, and support tissues.

LOWER LIMB BUD
appears on day 32.

THE FORMATION OF THE EXTERNAL EAR



THE ARM
is developed but is still missing the complete formation of the fingers.

Arms and Legs

Small buds begin to appear that will grow until they form the arms and legs. Up to this moment, the arms are in their right place and will remain in proportion to this stage of development. They are only missing the development of the hands. The legs begin to develop, but they take longer than the arms and hands.

Day
36

LENGTH: 0.4 inch (9 mm)
WEIGHT: 0.002 ounce (0.05 g)

THE FOLDS OF THE BRAIN develop as the months of intrauterine life go by.

1 SMOOTH BRAIN
Initially the embryonic brain has a smooth surface.

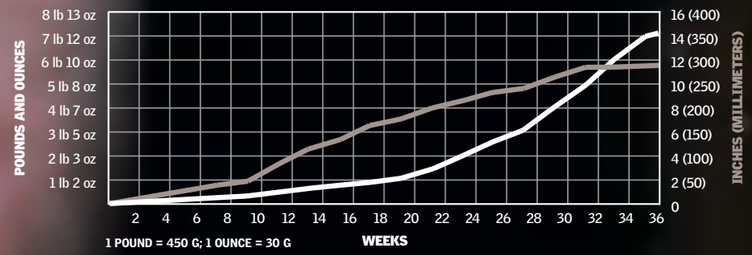
2 A FEW FOLDS
By six months, some basic folds can be seen.

3 ADULT
The complete folds allow optimal functioning.

The External Ear

Three auricular hillocks can be found in the first arch and three more in the second. As the jaw and teeth develop, the ears move up from the neck toward the sides of the head. Two ectodermic derivations appear in the cephalic region of the embryo: the otic placode and the lens placode. At birth, the external ear exhibits its typical shape.

GROWTH OF THE FETUS



FEATURES BECOME DISTINCT

1 Lower jaw
begins to develop by day 37, together with the lips.

2 Nose
is roughed out by the invagination of the frontonasal prominence on day 39.

3 Chin
is already proportional by day 40. The nose has acquired its definitive shape.

Formation of the Face

The facial characteristics are quickly delineated. The pharyngeal arches that surround the stomodeum in the center of the face are configured. The mandibular processes and the frontonasal prominence can already be identified. From the pharyngeal arch, the maxillary process will also develop, which will give rise to the premaxillary, the maxillary, the zygomatic bone, and part of the temporal bone. At the roof of the embryo's mouth, the primitive palate is constructed. Through an invagination in the frontonasal prominence, the nose is shaped. The same thing happens with the chin, which acquires normal proportions by day 40 of intrauterine life.

4 The shape of the face has begun to develop and will continue to do so until the third month.

Eyes

The optical vesicles develop on both sides of the head, move toward the center, and form the eyes, as will the ducts that will make up the inner ear.

Day
40

LENGTH: 0.4 inch (10 mm)
WEIGHT: 0.004 ounce (0.1 g)

Day
44

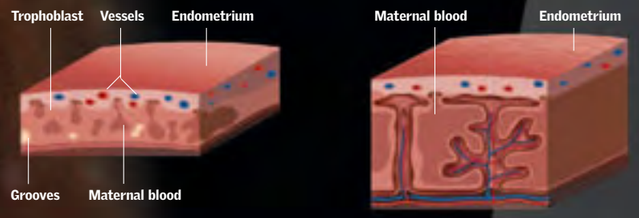
LENGTH: 0.6 inch (16 mm)
WEIGHT: 0.02 ounce (0.5 g)

Changes in the Brain

At this stage, the brain connects with the nervous system. The gland responsible for the production of the hormones begins to develop in it.

1 FORMATION OF THE PLACENTA
The cells of the trophoblast extend inside the blood vessels of the uterus. The blood from the mother flows from these vessels toward empty spaces inside the trophoblast.

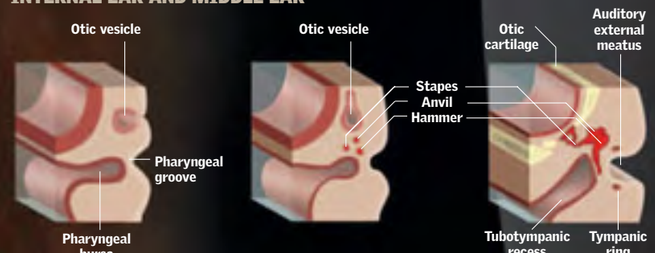
2 THE PLACENTA AS FILTER
The mother's blood and that of the fetus do not have direct contact inside the placenta. They are separated by a barrier of cells. Oxygen, nutrients, and antibodies travel through the barrier and reach the fetus. The waste is returned to the placenta.



Development of the Placenta

The placenta is a special organ that provides the fetus with different nutrients and oxygen. It also absorbs the waste that the fetus produces and acts as a protective barrier against any harmful substances. The placenta forms from the trophoblast, the external layer of the blastocyst (mass of cells implanted in the uterus after fertilization). It begins to develop after implantation, and by the tenth day, it is complete. The placental hormones help preserve the endometrium.

INTERNAL EAR AND MIDDLE EAR



1 22 DAYS
A visible groove appears in the place where the ear will be.

2 28 DAYS
The structures that will give rise to the bones of the middle ear appear.

3 32 DAYS
The middle ear is formed (stapes, anvil, and hammer).

The Pregnancy Test

A short time after fertilization, the placenta releases a hormone called human chorionic gonadotropin (HCG). The appearance and rapid increase in the concentration of this hormone in the urine are indicators of the existence of a pregnancy. A common pregnancy test contains antibodies that react to the presence of HCG. The user places the tip of the testing device in contact with her urine and waits an indicated amount of time. The presence of two lines in the display will indicate the existence of a pregnancy, while a single line will indicate the opposite. If the test is negative, repeating the test is recommended.

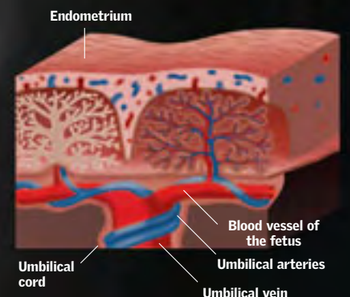
HOW IT WORKS

ABSORPTION OF URINE
An absorbent tip is placed under the urine stream for six seconds, until it is moist.

RESULT
Two lines indicate the presence of pregnancy. If there is only one, it is recommended the test be repeated within 48 to 72 hours.

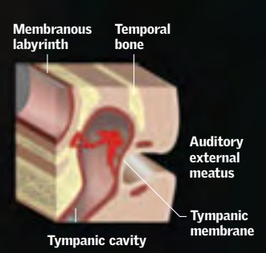
99%
EFFECTIVE IN DETECTING PREGNANCY

3 END OF THE PLACENTA
The placenta continues its development as the fetus grows, such that, by the end of the pregnancy, it measures about eight inches (20 cm). It is connected to the baby by the umbilical cord.



6 weeks

THE FINGERS APPEAR Although the hand has a shape resembling a small paddle, the digits are becoming distinct.



4 60 DAYS
The auditory external meatus develops from the pharyngeal groove.

Everything in Place and Working

During this period, the brain and the nervous system develop rapidly. On both sides of the head, the optic vesicles that will make up the eyes have formed, as have the ducts that will make up the inner ear. The heart already beats strongly, and the digestive and respiratory apparatus have begun to take shape. Small buds that will grow to form the arms and legs appear. The fetus, measured from the top of the head to the coccyx, by the sixth week will have reached 0.6 inch (16 mm).

BRAIN
After 51 days, the fourth ventricle of the brain controls the flow of blood, and the circulatory system begins to develop.

THE THALAMUS
The skull begins to form. On day 52, the thalamus develops and can be distinguished. The eyes move toward the front.

THE EAR
begins its development in the fourth week but will not be complete until the sixth month, when it carries out the function of bodily equilibrium.

INTERNAL ORGANS
At this stage, all the essential organs begin to develop in the gastrointestinal, respiratory, and reproductive systems.

Day
60

LENGTH: 1.2 inches (3 cm)
WEIGHT: 0.1 ounce (3 g)

Fetal Development and Childbirth

FIRST TRIMESTER
Picture of an eight-week-old baby. The development of the brain, heart, and extremities can be noted.

NEURON DEVELOPMENT 24-25
BOY OR GIRL? 26-27
GROWTH BEGINS 28-29
INTENSE MOVEMENTS 30-31
REFINEMENT OF HEARING 32-33
CLOSER WITH EVERY MOMENT 34-35
CRUCIAL MOMENTS 36-37
FORTY WEEKS OF SWEET ANTICIPATION 38-39
CHILDBIRTH, ONE MORE STEP 40-41
AFTER CHILDBIRTH 42-43
AN ANSWER TO THE RESEMBLANCE 44-45

The fetus's growth continues progressing day by day, and this chapter illustrates the most notable changes that can be seen. By now, it is possible to distinguish ovaries from testicles, to observe the external parts of the ear, and to see the limbs flex. We will also use pictures to tell you about DNA, the key substance of the body that enables hereditary characteristics to be passed from one generation to the next. Which tests must pregnant women take to find out if fetal development is normal? What are the most notable changes that the woman's body goes through, and what happens once the baby begins to breathe and live outside the womb? ●

Neuron Development

The third month of fetal development brings distinct changes compared with previous stages. What was once called the embryo is now a fetus. The number of neurons in the brain increases rapidly, and toward the end of the month the fetus has the same number of nerve cells as an adult. However, the interneuron connections have not been established. During this month, through nerve impulses, the network will take shape, which in later months will allow voluntary movements of the joints.

100 billion neurons are formed between the third and seventh months of fetal development inside the mother's womb.

THE AXON
Nerve fiber that extends from the cell and transmits nerve impulses

MYELIN ENVELOPE
Fatty layer that insulates the axons of some neurons and accelerates the transmission of impulses

SYNAPTIC NODE
Axon terminal. Contains chemical substances (neurotransmitters) that transmit nerve impulses.

1 Electrical conduction

Nerve impulses travel through neurons as electrical impulses caused by changes in the ionic concentration inside and outside the cells.

NEURON NUCLEUS
contains the genetic information to synthesize the necessary substances for the nerve cell.

CELL BODY
The neurotransmitters that transmit nerve impulses are synthesized here.

DENDRITES
are projections of the neuron that capture and receive the nerve impulses of the other neurons.

FROM NEURON 1

Electrical impulse

NEURON 2

2 Chemical conduction

The neurons connect through synaptic spaces, where the impulses are conducted chemically through the release of neurotransmitters.

SYNAPTIC VESICLE

AXON TERMINAL

IONS

NEUROTRANSMITTERS

SYNAPTIC GROOVE

OPEN CHANNEL

3 Synaptic connection

The electrical impulse reaches the vesicles. The neurotransmitters are released into the synaptic gap and travel to the second cell. The impulse is transmitted electrically.

TO NEURON 3

Chemical Conduction

Chemical conduction occurs when there is transmission between neurons. It works through the so-called neurotransmitters, or chemical messengers, of nerve impulses. The neurotransmitters, which are stored in vesicles (small receptacles in the nerve endings), are released when an electrical signal reaches the nerve ending (electrical conduction). The transmitters travel from the synaptic node of the neuron to the cellular membrane of another cell, which in turn contains receptors that receive the released chemicals. These electrically charged particles (ions) enter the new nerve cell and initiate a new impulse that will be sent to another neuron.

Neuron

The neuron is the most important cell in the nervous system. Through the transmission of nerve impulses, they establish connections to other neurons to make the brain function.

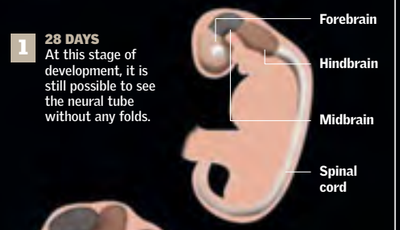
The Nervous System

In the third month of gestation, the fetus's developing brain changes significantly compared with previous stages. Toward the end of the month, it will have the same number of nerve cells as an adult. The nerves that run from the brain begin to be covered with myelin, a protective lipid layer that insulates the axons of some neurons to speed the transmission of impulses. The nerves and muscles begin to establish connections, setting the foundation for movement controlled by the cerebral cortex. Although the fetus can make a fist and clasp its hands, the movements are still involuntary since the nervous system is not complete.

640 miles per hour (400 km/h)
IS THE SPEED AT WHICH MATURE CELLS OF THE NERVOUS SYSTEM TRANSMIT ELECTRICAL IMPULSES.

Formation of the Brain

Developing from folds in the neural tube, the brain finishes taking shape by the third month. Later it will develop the folds of the cortex.



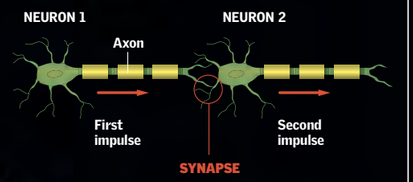
1 28 DAYS
At this stage of development, it is still possible to see the neural tube without any folds.

2 49 DAYS
An increase in brain size can be seen, and the general structure of the embryo begins to take shape.

3 3RD MONTH
We now see a real fetus. The brain attains its definitive shape, but the cortex is still developing.

Electrical Conduction

The nerve impulses inside a neuron travel as electrical impulses. After an electrical impulse is generated, it travels through the axon. This conduction is produced by the exchange of calcium and potassium ions along the length of the nerve cell membrane.

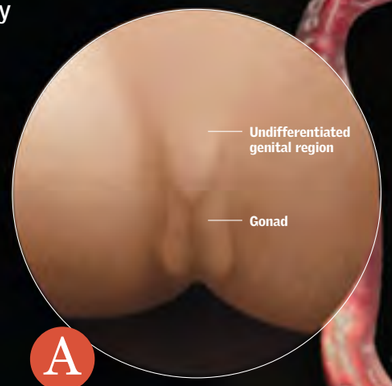


Boy or Girl?

By the third month of pregnancy, the mother may be anxious to find out if the unborn baby will be a boy or a girl. Although the sex of the fetus has been determined genetically since fertilization, it still cannot be observed at this early stage of development. By the second trimester, at about 12 weeks, the fetus's genitals begin to appear but still cannot be distinguished as being male or female. The initial undifferentiated bulge has a particular shape that allows it to turn into either a penis or a clitoris.

Sex Is Defined

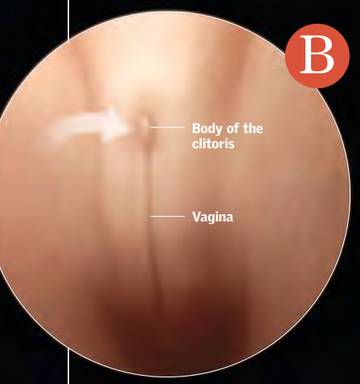
Until the fifth week after fertilization, the embryonic sex organs of boys and girls are identical. Genetically, sex has already been defined, but under a microscope, the genital regions are indistinguishable. The female and male genitals are not yet differentiated. In the third month, the initial bulge that has developed has a characteristic form and is shaped in such a manner that it can turn into either a penis or a clitoris, with the usual characteristics of either. The genitals have a groove in the urethra that is distinctive. If this groove closes, then a boy is on its way. If it stays open, then the baby will be a girl. The genitals of the fetus, then, begin to grow in the fourth week, becoming visible and external in the eighth week. However, the sex will not be distinguishable until after the 12th week.



A

Undefined

Each embryo has an undifferentiated genital system and the structures necessary to develop into either sex. The gonads are sexually undefined and have both male and female components.



B

If It Is a Girl

The vulva (which contains separate openings for the vagina and urethra) and the vagina develop from the same common structures. The clitoris will begin to form from a bulge in the urogenital sinus, the genital tubercle. The intervention of hormones is key in influencing the differential formation of each organ. The evolution might be different, but the origin is exactly the same.

If It Is a Boy

By the 11th week, the genital tubercle lengthens rapidly and forms the penis. The components of what will be the genitals are progressively modified and form the elements that define the external genitalia of the male—testicles, scrotum, and penis.

C

THE CORD
is completely mature and is rolled up so that the baby can move around without any risk.

3.5 inches (9 cm)

SECOND TRIMESTER
By the beginning of the second trimester, the fetus measures 3.5 inches (9 cm) long.

Month 3

LENGTH: 4 inches (10 cm)
WEIGHT: 1.6 ounces (45 g)

THE HEAD
is still disproportionately large in relation to the body. It represents a third of the length of the fetus's body.

THE EYES
are completely formed, although they are very far apart. They have been slowly moving toward the front of the head throughout embryonic and fetal development.

THE HANDS
already have fully developed fingers. They have fingernails and the shape of human extremities.

The Sperm

According to popular belief, to conceive a boy one must have sex on the day the woman is ovulating or the day after, since sperm with a Y chromosome (determinant of the male sex) are quicker than those that contain the X chromosome (female) and reach the egg first. If the desire is to have a girl, it is best to have sex a few days earlier: X sperm are slower, but have more endurance and live longer.

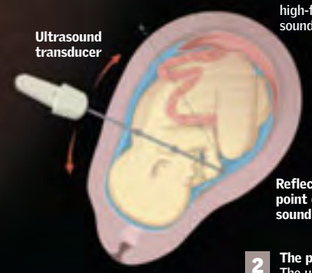
LIFE COMPARISON

The sperm with an X chromosome are slower but have more endurance. They can last up to 72 hours. The sperm with a Y chromosome, on the other hand, are quicker but last only approximately 48 hours.

The Sonogram

An ultrasound image, also known as a sonogram, uses inaudible sound waves to produce images of the different structures of the body. During the examination, a small device called a transducer is pressed against the skin. It generates high-frequency sound waves that pass into the body and return as echoes as the sound waves bounces against organs, blood-vessel walls, and tissues. A special computer converts the echoes into an image.

HOW A SONOGRAM IS MADE



1 **Transmission of impulses** The ultrasound transducer emits high-frequency sound waves.

2 **The path** The ultrasound impulses pass through the body's tissues and bounce off surfaces.

3 **Detecting the echo** Some impulses are reflected as echoes that the wand picks up and sends to the sonograph.

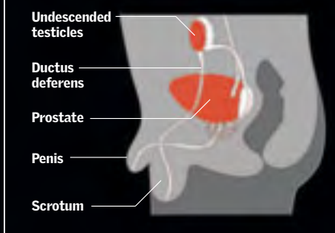
FORMING THE IMAGE
The sonograph calculates the distance from the wand to the tissues, the echo intensity, and the return time of each echo in millionths of a second. Some sonographs show three-dimensional images. They show the entire surface of the fetus and help to identify any deformation.

Growth Begins

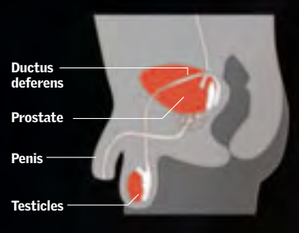
During the fourth month, the mother senses the fetus's first movements. The fetal body changes; its face is completely formed. The skin has a pinkish tone, and the first ribs and cartilage appear. The external sex organs finish forming, and the internal ones differentiate. The first subtle movements of the fetus begin, although they are barely perceptible because of its small size. The fetus now occupies the entire uterine cavity and pushes the abdomen forward. Its extremities can be clearly seen. The little one enters its full growth phase.

Sex Development

During this period, the fetus begins to reveal the differences in its urogenital system. The undifferentiated gonad, which has male and female components that developed during the embryonic stage, is converted into ovaries in a girl or testicles in a boy. In either case, its presence will determine the development of the individual's sexual characteristics.



1 MALE GONAD
Toward the seventh week, it has already been determined whether the fetus is XY (male) or XX (female). If a gonad is evolving into a testicle, the undifferentiated gonad increases in size as it descends into the scrotum.



2 DESCENT OF THE TESTICLES
At about the eighth week, the testicles leave the abdominal cavity and descend toward the scrotum. For males, the presence of the testicles and the actions of their hormones are necessary.

Amniocentesis

is a test that is performed by studying the amniotic fluid in the sac that surrounds the fetus. After the insertion of a hollow needle into the abdominal wall of the uterus, a small amount of liquid is extracted. It is not a routine test, and it is invasive. It is done when there is suspicion of abnormalities that cannot be detected with other tests (e.g., tests for spina bifida or metabolic diseases).

COMPONENTS OF THE AMNIOTIC FLUID

98 % water

2 % Organic solutes: proteins, lipids, carbohydrates, and nonprotein hydrogenated components. **Inorganic solutes:** zinc, copper, iron, and magnesium.

Chromosomal Study

Amniocentesis gives a cytogenetic map (map of chromosomes) from which different chromosomal disorders can be detected, such as Down syndrome (an extra chromosome in pair 21) or the existence of an abnormal gene that can cause neurological or metabolic diseases.

160

is the number of heartbeats per minute in the early stages of intrauterine life. Toward the end of gestation, the number drops to 120.

LOWER LIMBS
In this stage, the legs grow rapidly in a proportional manner and are longer than the arms.

The Taste Buds

develop at this stage, although they are activated only in the last trimester of gestation. The tongue has approximately 10,000 taste buds.

THE TONGUE

Month **4**

LENGTH: 5.9 inches (15 cm)
WEIGHT: 5.3 ounces (150 g)

Changes in the Brain

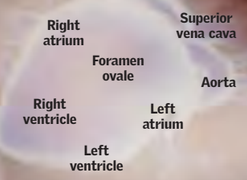
The brain continues its growth and starts to develop folds. During most of the intrauterine period, many neuron cells are produced per second. A large portion of energy will be concentrated solely on the development of this vital organ. The areas of the brain that show the greatest growth at this stage are those that control motor skills and memory. The regions that control the basic urges such as hunger are also forming.

MOTOR CORTEX
will send signals to the muscles to move the body.

PREMOTOR CORTEX
will coordinate more complex movements, such as playing musical instruments.

FINGERS
The fetus's genetic uniqueness also starts to become evident in the development of its fingerprints.

EARS
The ossicles (tiny bones) begin to harden. The fetus can sense its mother's voice and heartbeat.



The Heart

At this stage, it beats at the mother's heart rate and pumps more than 6 gallons (25 l) of blood each day. Its size is large relative to the body. The foramen ovale in the fetal heart is a hole that allows the blood to circulate from the right atrium to the left one. It will close during the first three months after birth.

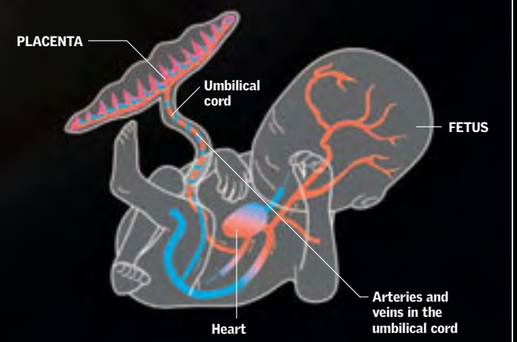
BONES
can be distinguished with X-rays and have begun to change from cartilage into calcified bones.

THE SKIN
is still translucent, thin, and wrinkled, and it allows the developing blood vessels and bones to be seen.

UPPER LIMBS
The fetus begins to move and flex the joints of its extremities.

Circulatory System

The fetus receives oxygen and nutrients from the placenta through the umbilical cord, so its circulatory system differs from that of a newborn baby. During intrauterine life, its heart is the center of a system interconnected with the lungs and liver through arterial and venous ducts that, after birth, will close and become ligaments.



Intense Movements

The fifth month of intrauterine life reveals marked changes: the fetus's movements are more obvious and intense and are perceptible to the touch. During this period, it is important to have ultrasound exams to check for the position of the placenta, the proper circulation between the uterus and placenta, and the risk of premature birth. The future baby's features are clearly visible.

Month 5

LENGTH: 79 inches (20 cm)
WEIGHT: 176 ounces (500 g)

Energetic Movement

Because of the accelerated growth and development of its internal organs, the fetus is much more active. It turns, moves from side to side, and finds ways to be more comfortable inside the uterus. It is exploring the surroundings where it lives, which makes its movements strong enough to notice. When she least expects it, the mother can receive a kick from the unborn baby. Anyone that gets close to the mother's belly can hear the fetal heartbeat through a special device.

LANUGO is the fine hair that appears in the fifth month of gestation. It covers the entire body.

THE HEAD is the part of the body that develops most actively. Eyes, mouth, nose, and ears are almost completely formed.

Exploration

It is very important for the mother to have prenatal tests done periodically to monitor for possible problems or abnormalities in the fetus. Different techniques can be used to verify the fetal position and the development of its features. Sonographs produce images of the internal organs or masses for diagnostic purposes. Three-dimensional magnetic resonance imaging (MRI) allows the diagnosis of previously undetectable diseases and pathologies. In addition, it is not harmful to the fetus. 4-D ultrasound allows monitoring of the fetus in real time.

MRI

Magnetic resonance imaging allows diagnosis of the fetal position when this is difficult to accomplish with other techniques. This can be helpful in planning for the birth. Unlike conventional X-rays, magnetic resonance imaging does not have harmful effects on the fetus because it does not emit any ionizing radiation. Use of the process is recommended from the moment a fetal abnormality is suspected until birth.

The umbilical cord and extremities are clearly visible in this MRI image.

4-D Ultrasound

Incorporating the dimension of time into ultrasound exams has made it easier to observe the fetus, since the parents can see it in three dimensions and in real time while it moves. The use of 4-D ultrasound is not limited to obstetrics; it is also a tool to check the status of other organs, such as the liver, the uterus, and the ovaries.

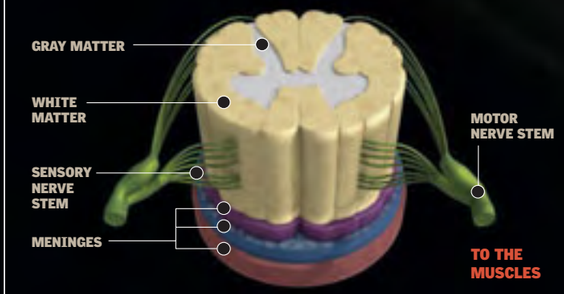
IN ACTION
The growing baby can be clearly distinguished in a three-dimensional ultrasound, which also allows fetal movement to be seen.

Spinal Cord

begins to develop in the fetus. The spinal cord will be the communication link between the brain and the rest of the body. The spinal cord receives and transmits information through the nerves. The nerve impulse stimulates the muscle to move.

MUSCLE MOVEMENT

1. The brain processes sensory data and sends information to the spinal cord.
2. The spinal cord receives the nerve impulse from the brain and sends a response to the muscle.



Internal Organs

are in a maturing stage and most are already formed. However, the lungs and the digestive system are not yet complete. The fetus cannot maintain its body temperature or survive outside the uterus.

AMNIOTIC FLUID The baby can swallow it and even taste the substances that float in it, because the taste buds are already developing.

Defense System

With its body and organs well formed, the fetus now enters a stage of maturation characterized by, among other things, the construction of a defense system. Fatty deposits accumulate and settle in different parts of the body, such as the neck and chest, to generate body heat and maintain the body temperature. The fetus also develops a fledgling immune system that will partially protect it from some infections.

A Song to Life

Even though the ear has not reached its peak development, it can already perceive sounds from the outside, besides those coming from the mother (heart, stomach sounds). The mother's physical state and her mood strongly influence the future baby, who can tell at all times if things are right or not.

Refinement of Hearing

During the sixth month of gestation, the ears exhibit their peak development. The fetus is sensitive to sounds outside the uterus and can hear very loud sounds. The cochlea, in the inner ear, is vital for processing sounds and already has attained its characteristic coiled shape. This is the month where the fetus prepares for life as an independent being.

Recognizing the Parents' Voices

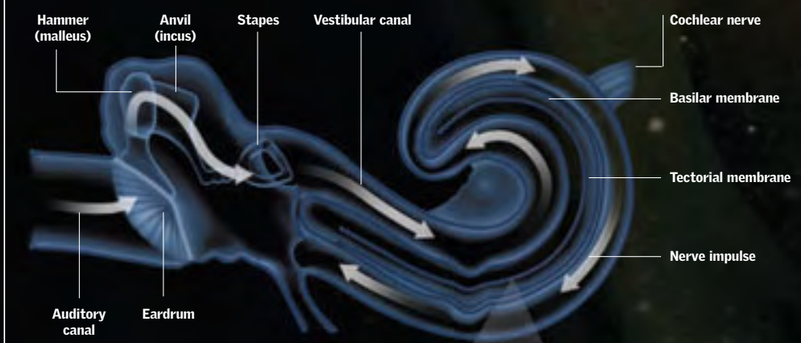
With the perfection of the sense of hearing, the baby not only can hear noises and voices from outside but also can memorize them. It can recognize both the mother's and the father's voices. Since the fetus can respond to external stimuli, the parents are usually recommended to talk and play music. It can also move to the rhythm of the music and shows musical preferences. With its eardrums fully developed and fully functional, the fetus can now hear sounds originating from itself, such as its heartbeat.

Balance

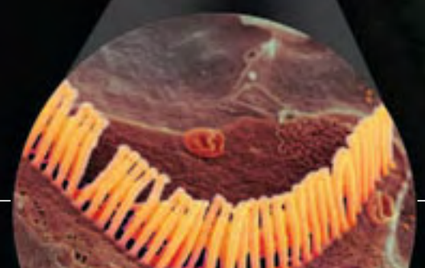
The functioning of the sense of hearing is essential also for understanding the sense of balance. The inner ear has fluid that sends nerve impulses to the brain to update the information about the body's movement and to maintain balance and posture.

0.1 in (3 mm)
THE SIZE OF THE STIRRUP, THE SMALLEST BONE OF THE EAR

SOUND WAVE PATH



1. Sound waves enter the outer ear canal and are transmitted to the eardrum.
2. The eardrum receives the sound waves as vibrations, which later reach the cochlea.
3. In the cochlea, the organ of Corti gathers the vibrations through hair cells.
4. Filaments in the cochlea are agitated and stimulate the nerves to send messages to the brain.



15,000
HAIR CELLS are in the organ of Corti. They convert the sound vibrations into nerve impulses, which travel to the brain to be processed as sound.

20
THE HOURS per day that the fetus sleeps. When awake, it is very active.

PRIMARY AUDITORY CORTEX receives incoming sounds.

ASSOCIATION CORTEX interprets the sound.

ENLARGED AREA

ENLARGED AREA

FLAVORS
The fetus can distinguish sweet and bitter flavors; of course, it prefers sweet.

HANDS
The first lines appear on the palms. The fingers can be seen.

KICKS
The joints are already developed and the baby kicks with rapid movements.

FEET
are defined and acquire their shape. The toenails become visible.

Month 6

LENGTH: 9.8 inches (25 cm)
WEIGHT: 2 pounds 3 ounces (1 kg)

CROSS SECTION OF THE UMBILICAL CORD

The Umbilical Cord

is the structure that connects the fetus to the placenta. It constitutes the immunological, nutritional, and hormonal link with the mother. It contains two arteries and a vein that regulate the exchange of nutritional substances and oxygen-rich blood between the embryo and the placenta. It is 12 to 39 inches (30-100 cm) in length, connects the fetus's navel to the placenta, and constitutes the first physical tie between the mother-to-be and the fetus. Usually there are no complications related to the umbilical cord, although there are cases where knots form that block the flow of blood. These knots can be deadly if they are not controlled or corrected.

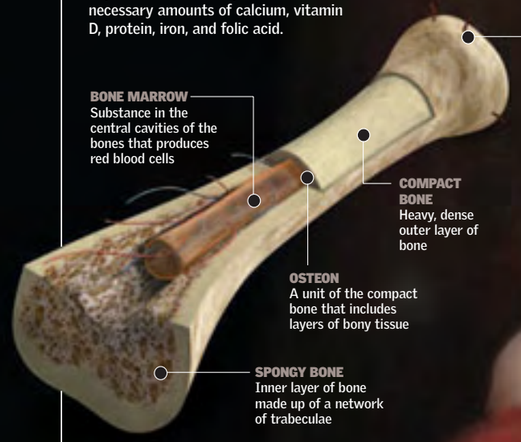
Closer with Every Moment

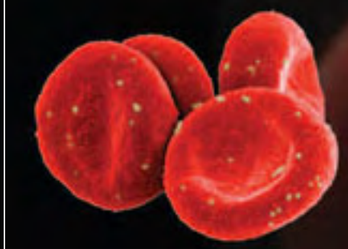
The beginning of the third trimester of pregnancy marks a key point in gestation. The process of strengthening and calcification of the bones of the fetus begins. Its body needs nutrients, such as calcium, folic acid, and iron. The baby can already open and close its hands (which will soon have defined fingerprints) and also opens and closes its mouth, sticks out its tongue, and can even suck its thumb. Its skin is still very thin but has begun to turn opaque. The bones and muscles begin to have more consistency. The organs are completely formed.

Bone Calcification

The baby's bones have begun the process of strengthening through the buildup of calcium and also phosphorus. Bone growth is regulated by many hormones. As the bones are getting harder, appropriate nutrition is important in order to provide the necessary amounts of calcium, vitamin D, protein, iron, and folic acid.

300 **THE NUMBER OF BONES IN A FETUS.** After birth and before reaching adulthood, the skeletal system goes through a fusion process that reduces the number of bones to 206.





Red Blood Cells

The production of blood cells develops in the longer calcified bones, such as the femur, in a liquid substance called bone marrow, which is found in certain bone cavities.

Month **7**

LENGTH: 12 inches (30 cm)
WEIGHT: 3 pounds 5 ounces (1.5 kg)

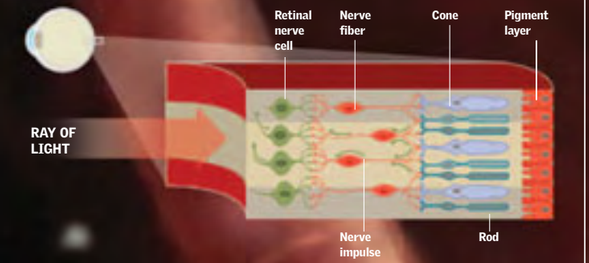
Central Nervous System

The folds in the cerebral cortex undergo rapid development that is more noticeable toward the end of the month. The body temperature and breathing are already controlled by the central nervous system, which controls the inhalation of air.

The Fetus Opens Its Eyes

The optical structure is practically fully formed. The fetus can open and close its eyes, which will keep their sky blue color until the second week after birth, since the definitive pigmentation is attained through exposure to light. With the general development of the eyes, the fetus can already distinguish changes from light to dark. It might also be able to see its hand clearly, since it puts it into its mouth with ease.

REACTION TO LIGHT



1 **Light enters** through the pupil and reaches the pigment layer in the retina.

2 **Nerve impulse** The cone and rod cells, when stimulated, transmit impulses to the fibers.

3 **Reception** The retinal nerve cells receive the impulse and relay the information to the brain.

Glucose Tolerance Test

In the seventh month of pregnancy, a crucial test is performed to detect the possible presence of gestational diabetes (diabetes that develops during pregnancy). In this test, called the Glucose Tolerance Test, or the O'Sullivan Test, a glucose load (about 1.8 ounces [50 g]) is administered orally to the fasting woman. An hour later, blood is drawn and the glucose level is measured.

THE SKIN is no longer transparent and takes on a more opaque color. Layers of fat begin to accumulate under the epidermis, which makes the skin smoother.

REFLEX The typical reflex of thumb sucking is perfectly developed by the seventh month.

Crucial Moments

The eighth month of pregnancy brings many obvious changes to the fetus. The lanugo disappears from the fetus's face, and the limbs become chubby. Birth is imminent, and before the month is finished, most fetuses assume a head-down position. The space in which the fetus has to move within the uterus is minimal, so during this time the fetus remains almost still. Except for the lungs, the organs are fully functional. That is why birth at this stage entails many risks.

Final Preparations

At the beginning of the eighth month, the unborn baby's kicks become increasingly forceful and frequent. The shifting toward its final position begins, which in most cases is cephalic (the head toward the pelvis), although sometimes it is breech (with the buttocks toward the pelvis). If the baby is in a breech position, a cesarean section might be necessary. It is common to do ultrasound exams at this stage to verify that the baby's weight is adequate.

1 Reduced Space

Since the fetus has reached a considerable size, it now has little room in which to move. Hence, it begins to turn and kick forcefully.

2 Cephalic Presentation

In 90 percent of cases, the fetus is positioned so that the head will come out first during delivery.

3 Final Position

The fetus has assumed its final position before delivery. Its buttocks will start pressing against the mother's diaphragm.

MECONIUM is a dark green substance that is found inside the intestine. It is the first thing excreted by the baby after birth.

ADRENAL GLANDS Located above the kidneys, the glands that produce adrenaline have already attained the size of those of a teenager.

THE SKIN is pink and smooth. The fetus continues to accumulate fat reserves in the epidermis. The hair that has protected it disappears.

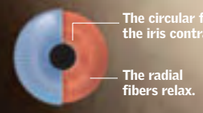
INTERNAL ORGANS are completely developed, except for the lungs, which have yet to be completely coated with surfactant.

SENSE OF TASTE The fetus drinks amniotic fluid and can already distinguish flavors with its developing taste buds.

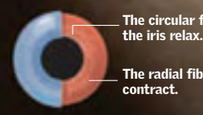
THE EARS are already mature. The fetus can perceive low sounds better than high ones.

EYESIGHT The fetus begins to blink. The iris can dilate and contract according to the light it receives, even though the fetus is not yet fully able to see.

WITH BRIGHT LIGHT



WITH LOW LIGHT

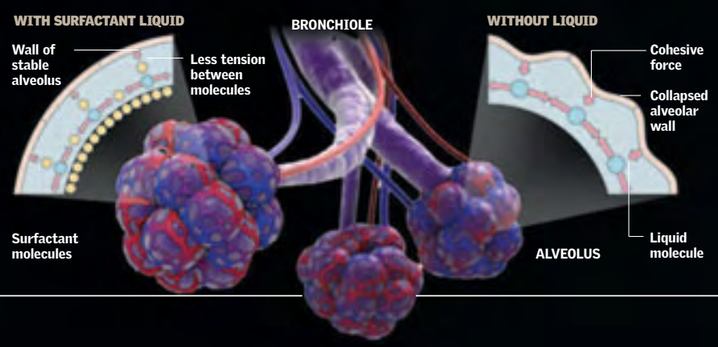


Month 8

LENGTH: 13.8 inches (35 cm)
WEIGHT: 5 pounds 8 ounces (2.5 kg)

Appearance of the Pulmonary Surfactant

In the eighth month of pregnancy, a substance called surfactant appears in the alveoli. This liquid covers the alveoli, which are surrounded by blood vessels and provide the surface for gaseous exchange. The surfactant maintains equilibrium in the lungs and keeps them from completely collapsing after every breath. With the presence of proteins and lipids with hydrophobic and hydrophilic regions, water is absorbed by the former regions and air is absorbed by the latter. A baby born at eight months can have problems because it lacks surfactant.



20 million

THE NUMBER OF ALVEOLI the fetus has before birth. Lung development will continue until eight years of age, and the child will end up having 300 million alveoli.

10

THE PROPORTION OF THE FETUS'S HORMONE PRODUCTION compared with an adult. After birth, the ratio decreases.

Rh Disease

When a baby's mother is Rh-negative and the father is Rh-positive, the baby can inherit the Rh-positive blood from the father. In this case, there is the danger that some of the baby's red blood cells may enter the mother's bloodstream. Red blood cells with the Rh factor are foreign to the mother's system, and her body will try to eliminate them by producing antibodies. The risk of this development increases after the first pregnancy.

Forty Weeks of Sweet Anticipation

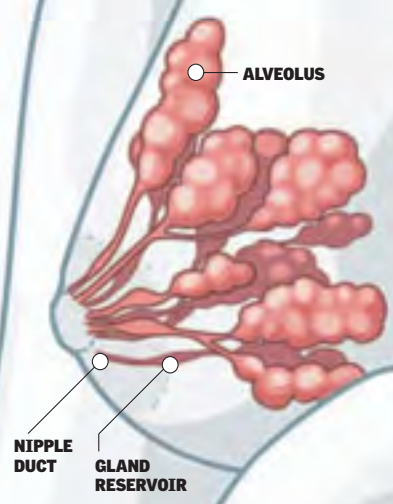
The pregnancy is reaching its end. During the last few months, besides the enlargement of the belly and breasts, the mother has undergone many psychological and emotional changes because of altered hormone levels. Now, a step away from birth, it is possible that she might not sleep well and may tire easily. Moreover, in this situation, certain fears and anxieties are common to every woman, so it is best to be well informed. ●

The Breasts

are made up of adipose tissue and a system of ducts that extend from the mammary glands to the outside. Along their length, they are covered by two layers of cells: an inner one (epithelial) and a discontinuous outer one (myoepithelial). At the beginning of pregnancy, the increase in the hormone progesterone triggers the enlargement of the breasts, which increase by one size in the first six weeks.

GALACTOPHOROUS DUCTS
The largest ones are in the nipple and branch out within the breast.

PHYSIOLOGICAL CHANGES
With pregnancy, they become larger and the nipple and the areola get darker, the skin on the breasts stretches, and the ducts widen.

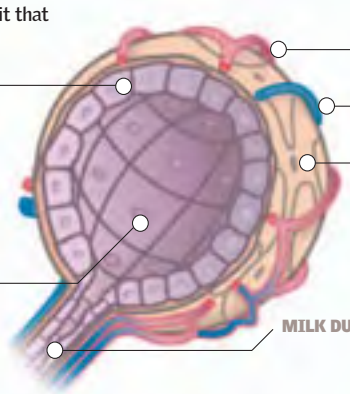


NIPPLE
The galactophorous ducts lead here.

AREOLA
Circular region 0.5 to 1 inch (15-25 mm) in diameter. It contains sebaceous glands. Its size varies with the pregnancy.

The alveolus

is the functional unit that produces milk.



MILK EJECTION
When the ducts contract as a response to oxytocin (let-down reflex), the milk flows inside the galactophorous, or lactiferous, ducts toward the reservoir of the mammary gland.

Breast-feeding

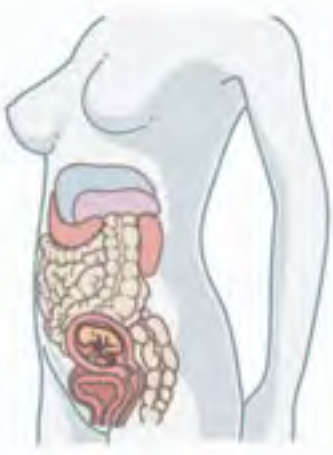
THE BABY IS NOURISHED NOT ONLY BY THE MILK BUT ALSO BY THE PHYSICAL CONTACT WITH ITS MOTHER.

MILK COMPOSITION

ELEMENTS	%
Water	87
Proteins	1.5
Casein	0.5
Fat	3.8
Carbohydrates	7.0
Other	0.2

Changes per Trimester

A pregnancy lasts 40 weeks, which by convention are divided into three trimesters. Each trimester corresponds to a series of more or less specific changes that come from the fetus's different developmental stages. Many of these transformations are painful, such as the pressure of the enlarged womb against the spine. There is also an increase in weight, dizziness, mood swings, and changes in heart rate.



1 First Trimester

During the first trimester of pregnancy, the body prepares to carry the fetus. The woman's breasts grow and their conditioning for breast-feeding begins. Dizziness and nausea are frequent during this period, the cause of which is not precisely known. Also normal is an increased need to urinate due to the activity of certain hormones that generate a need to empty the bladder repeatedly. It may also be apparent that the waistline is beginning to fade.

2 Second Trimester

is the period when if first becomes noticeable that the woman is pregnant. The uterus now extends from the pubic bone to the navel, and the belly is noticeable. The heart rate is altered by changes in the circulatory system. Varicose veins can also form in the legs due to the difficulty blood has returning through the veins from the lower limbs.

40%
MORE BLOOD IS PUMPED BY A PREGNANT WOMAN'S HEART.

3 Third Trimester

The skin stretches over the belly and very soft contractions begin to be felt. The uterus has grown and pushes on the bladder, which in some cases causes incontinence. In this period, back pains become more recurrent. The large volume of the belly can often cause deformations of the spine. In some women, breathing difficulties and repeated fatigue can develop. It is also normal to develop hemorrhoids.

VITAL CHANGES

1. **Menstruation is interrupted**
Women with regular periods (between 28 and 30 days) can notice this more easily.
2. **Discomfort**
Itching of the breasts, nausea, dizziness, and tiredness, even before the first month is finished
3. **The uterus expands**
At eight weeks, this is perceptible through a gynecological exam.
4. **Movements are felt**
Beginning in the fourth month, it is possible to perceive the movements of the fetus's hands and feet by ultrasound.

NEW LIFE
has grown from a mere embryo, and the woman's entire belly grows to accommodate this increase in size.

Childbirth, One More Step

Finally, the long-awaited day has arrived—the end of gestation and the moment of delivery. Labor is said to begin with the onset of regular uterine contractions. Labor has four stages: dilation, expulsion, delivery proper, and delivery of the placenta. With each contraction, a little more of the baby's head appears, and after about 15 minutes, the rest of the body comes out by itself and the umbilical cord is cut. ●

Labor

The labor process of birth is a joint effort between the fetus and the mother. Labor is divided into four stages: dilation, which starts with the contractions; expulsion, in which the fetus travels down the birth canal; delivery; and delivery of the placenta. Once the umbilical cord is cut, the newborn begins to breathe independently with its own respiratory system.

1 Dilation

As the mother's uterus begins to contract, the upper part of the fetus is pushed downward. The fetus begins its descent. Its first stop will be the pelvis before it reaches the birth canal.

Month 9

LENGTH: 19.7 inches (50 cm)
WEIGHT: 6 pounds 10 ounces (3 kg)

SIDE VIEW

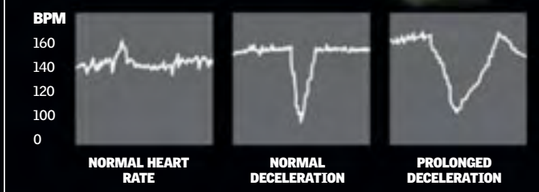
AMNIOCHORIAL SAC
is filled with amniotic fluid, which protects the fetus and provides it with space for movement.

OBLIQUE DIAMETER
4.3 inches (11 cm)

DIAMETER OF OPENING
3.5 inches (9 cm)

Fetal Monitoring

During labor, the fetus's heart rate, between 120 and 160 beats per minute, is monitored. The rate decreases with each contraction and then returns to normal. If this does not happen, it could be problematic.



2 First obstacle

The pelvis is the first obstacle that the fetus must face. To overcome it, the fetus adjusts its head according to the largest diameter, the oblique one, which is normally 4.3 inches (11 cm).

Contractions

The regular and frequent contractions of the uterus generally appear on the date of delivery. They are indispensable for childbirth to be natural and spontaneous. The uterus is a muscle, and each contraction shortens the muscle fibers of the cervix and contracts it to open it. The stage of contractions is the first phase of labor and the most important. If it proceeds normally, the baby will come out of the uterus naturally and begin its journey to the outside. Without contractions, the mother will not be able to push the baby, and it will be necessary to resort to assisted-labor techniques.

PUSHING THE FETUS

1. In preparation for delivery, the mother's uterus begins to contract at short intervals.
2. The mother's uterus contracts, putting more pressure on the upper part and pushing the fetus, which begins its descent.
3. The opening of the cervix dilates gradually with each contraction. The dilation is complete when it reaches 4 inches (10 cm).

THE CERVIX

The contractions of the uterus cause the gradual dilation of the cervix. It dilates completely when the opening is 4 inches (10 cm) in diameter. From this moment, labor passes to the second stage. The amniotic membranes can rupture at any time.

Relaxation

After each contraction, the mother should be able to relax the uterus so that the fetus gets enough oxygen. Without relaxation, the amount of blood reaching the fetus is reduced because the uterus flattens the blood vessels as it contracts.

THE SKULL

Until 18 months after birth, the skull will have cracks between its bones that will later fuse.

3 Birth Canal

The fetus finds that the birth canal has stretched. It rests its head on the pelvis and pushes against it. It pushes on the coccyx and is able to get its head out.

0.4 inch (1 cm) per hour

is the rate of cervix dilation for first-time mothers. The rate increases with subsequent births.

The Pelvis

It is important to know the shape and size of the future mother's pelvis to determine how difficult delivery will be. Any difference between the dimensions of the mother's pelvis and the unborn baby's head could obstruct normal delivery.

ROUND PELVIS
is the most common pelvis shape. Sometimes it may be oval-shaped. The pelvic exit usually has a diamond shape.

TRIANGULAR PELVIS
In some cases, the pelvic entrance is triangular and the exit is narrower. Delivery is more complicated in these cases.

4 Exit to the outside

Once the head passes through the birth canal, the baby passes its shoulders, one at a time. The rest of the body comes out without difficulty. Finally the umbilical cord is cut.

Less Pain

Certain natural techniques, such as relaxation and deep breathing, can help the mother experience less pain during childbirth. In other cases, a mixture of half air, half nitrous oxide can be administered by the doctor through a mask at the beginning of each contraction. Another option is the use of epidural anesthesia to relieve pelvic pain. This anesthesia is inserted through a needle into the spinal canal. Epidural anesthesia numbs the nerves that feed the pelvis and lower abdomen. This type of injection reduces the possibility of the mother's feeling the contractions.

After Childbirth

Once the baby is born, many changes take place in the child and in the mother. After the umbilical cord is cut, the baby begins to breathe on its own, and its circulatory system is autonomous. For the mother—in pain, with breasts full of milk, and a crying baby—the situation can be stressful. At this new stage, the best thing for the brand-new mother is to rely on her intuition to understand what it is that this much-anticipated baby needs. At the same time, the presence of an involved father will favor the development of a deeper and more intense bond with the child.

Changes in Circulation

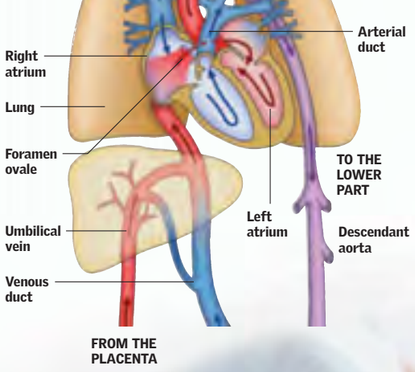
The fetus's circulatory system, which receives oxygen and nutrients from the placenta, is different from that of the baby after its umbilical cord is cut. The fetus's heart, which receives blood from the mother through the cord, has an oval opening called the foramen ovale. This hole, which allows blood to flow from the left atrium to the right one, closes after birth. The arterial duct, a tube that takes blood from the lungs to the aorta, also closes. The same happens with the umbilical blood vessels. When these ducts close, those that remain in the newborn's circulatory system become ligaments.

BEFORE THE UMBILICAL CORD IS CUT

1 The oxygenated blood enters the right atrium through the umbilical cord.

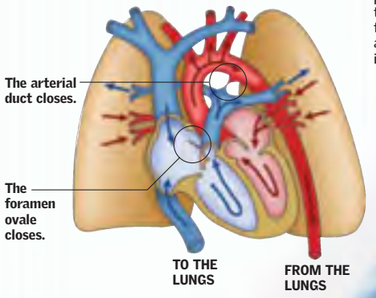
2 Since the lungs are contracted, they exert pressure in the opposite direction to that of the blood and force it to change direction.

3 The blood reaches the aorta mostly through the foramen ovale and, to a lesser extent, through the arterial duct. Once in the aorta, the blood is distributed throughout the body. This brings oxygen and nourishes the fetus.



AFTER THE UMBILICAL CORD IS CUT

4 Upon the cutting of the umbilical cord, the baby stops receiving blood from the mother.



5 The newborn takes its first breath and fills its lungs with air for the first time. The direction of blood flow reverses.

6 Blood is oxygenated in the lungs and reaches the aorta through the pulmonary veins. At the same time, the foramen ovale closes and a ligament forms in its place.

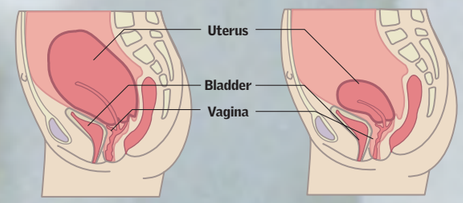
Hormonal Changes

During pregnancy, the levels of prolactin, a hormone produced in the anterior lobe of the pituitary gland (hypophysis), increase. This hormone remains at high levels while the mother breast-feeds. Prolactin is the hormone that causes milk production in the mammary glands. Another hormone released after pregnancy is oxytocin. Oxytocin brings on a reflex that causes milk to come out of the nipple. It is produced in the posterior lobe of the pituitary gland. The secretion of both prolactin and oxytocin, vital hormones in breast-feeding, is stimulated when the baby sucks on the breast. Milk production increases as the baby grows and requires more milk for feeding.

7.9 gallons (30 liters) is the average amount of milk produced by the mother in a month. The breast milk contains lactose (a type of sugar), proteins, and fats.

Everything Returns to Normal

During the postpartum period, the genital tract gradually returns to its state prior to the pregnancy. The uterus expels the remaining placental tissue in the form of a liquid called lochia, which is red at first, but later takes on a whitish color. The vagina gradually returns to its original size.



1 After birth, within a month, the placental site has healed, but the uterus is still distended.

2 Until the uterus returns to its original size, contractions continue and can be painful.

Sexual Disorders

The months after childbirth are usually traumatic for the sex life of the couple. In the beginning, sexual desire may be diminished due to the place assumed by the baby as the new center of attention. Moreover, in the first three months after childbirth, there may be vaginal dryness stemming from a lack of lubrication caused by hormonal changes. It is also normal for intercourse to be painful because of the scarring of wounds caused by the delivery. It is all a matter of time—time to readjust to the new situation, to give oneself permission to experience new sensations.

An Answer to the Resemblance

The baby has the mother's eyes but the father's hair color; the nose is like the grandfather's, and the mouth is like the grandmother's. These and other possible combinations are caused by genetic inheritance. The genes transmitted by the father combine with genes in the mother's egg, forming a single cell that will turn into a new human being. Through cell division during the baby's growth inside the uterus, the genes will expand, and the dominant ones will impose themselves over the recessive ones. In the case of twins, the physical resemblance results because they share the same genes.

The Genes

Each human cell (except for a few, such as red blood cells) has a nucleus. Inside the nucleus are the genes, contained in the chromosomes. Each cell nucleus has 46 chromosomes with the person's genetic information. Each gene has information with a code that determines a function in the body, such as hair color. Each living being has its own genetic identification, and the genes ensure that the individual grows and functions in a certain way.

MODEL DNA CHAIN

DNA STRUCTURE
The DNA molecule consists of two strands that twist around one another and form a double helix. Joining the two strands are four types of nucleotide bases that face each other in a specific and complementary way and provide a cell's instructions.

GUANINE (G)
ADENINE (A)
THYMINE (T)
CYTOSINE (C)
Phosphate group

1 DNA Strands

Every strand is made of a sequence of nucleotides. Each nucleotide is composed of a phosphate group, a sugar, and a nitrogenated base.

25,000
GENES ARE CONTAINED IN THE NUCLEUS OF EACH CELL IN THE HUMAN BODY.

2 The Bases

face each other when the strands are lined up opposite one another. Adenine is always matched to thymine and guanine to cytosine.

INSTRUCTIONS
The sequence of the nucleotide bases (adenine, cytosine, guanine, and thymine) determines the message that will be transmitted.

COMPLEMENTARY DNA CHAIN

Chromosomes

are like long, thin threads, rolled into an X-shape, that contain DNA. The genetic information is stored inside them. Their characteristic shape helps in the transmission of genes to the next generation. Each cell contains a total of 46 chromosomes arranged in 23 pairs. To form gametes, the cell divides twice, resulting in cells with 23 chromosomes instead of 46. When the sex cells join, the cell they create is a zygote, which has the 46 chromosomes necessary to form a human being.

WOMAN
The normal karyotype of women is 46XX.

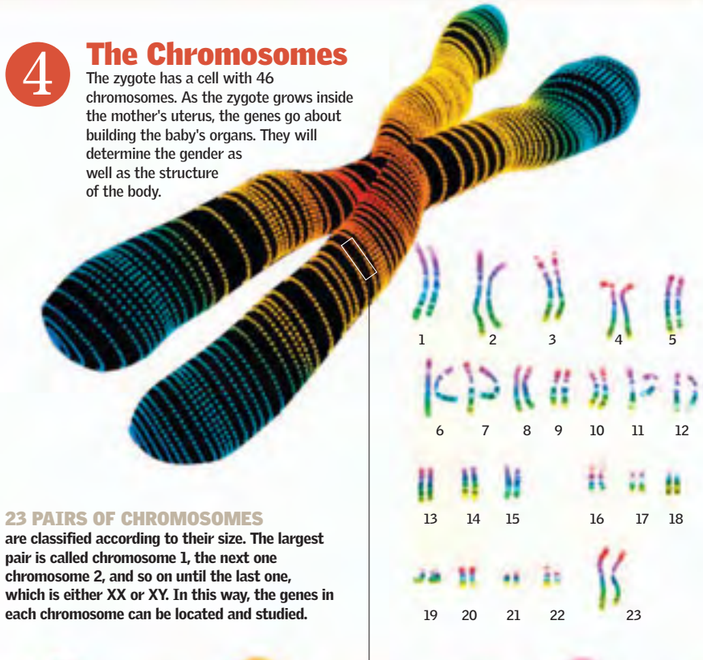
MAN
The normal karyotype of men is 46XY.

3 Double helix

The most common structure of DNA, a double helix, is formed from the union of two chains.

4 The Chromosomes

The zygote has a cell with 46 chromosomes. As the zygote grows inside the mother's uterus, the genes go about building the baby's organs. They will determine the gender as well as the structure of the body.



23 PAIRS OF CHROMOSOMES
are classified according to their size. The largest pair is called chromosome 1, the next one chromosome 2, and so on until the last one, which is either XX or XY. In this way, the genes in each chromosome can be located and studied.

DNA STRUCTURE

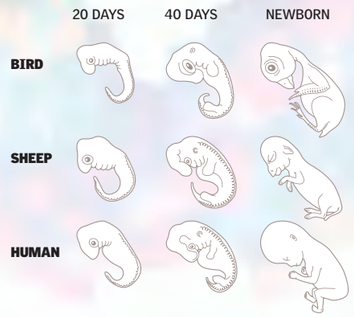
Identical and Fraternal Twins

It is estimated that one in 70 childbirths produces either identical (monozygotic) or fraternal (dizygotic) twins. Identical twins have the same genes and therefore are alike and of the same sex. They come from one fertilized egg. In some cases, twins share the placenta. Fraternal twins, on the other hand, are the same in age but not in genetic material. They come from two eggs that are released at the same time and are fertilized by different sperm.

Resemblances

If one observes different vertebrate embryos, the similarities between them are notable. These resemblances reveal that they are all descended from a common ancestor. The development of the body parts is marked by very similar genes. Morphologically all embryos possess a segmented tail, a heart with two cavities, and branchial (gill) clefts. The greatest difference appears in fish, which retain the branchial clefts. In other groups (amphibians, birds, mammals), one of the clefts transforms into the ear canal and the other into the eustachian tube. In spite of the changes in outer appearance, the observable patterns of internal organization tend to be preserved.

GENETIC DEVELOPMENT



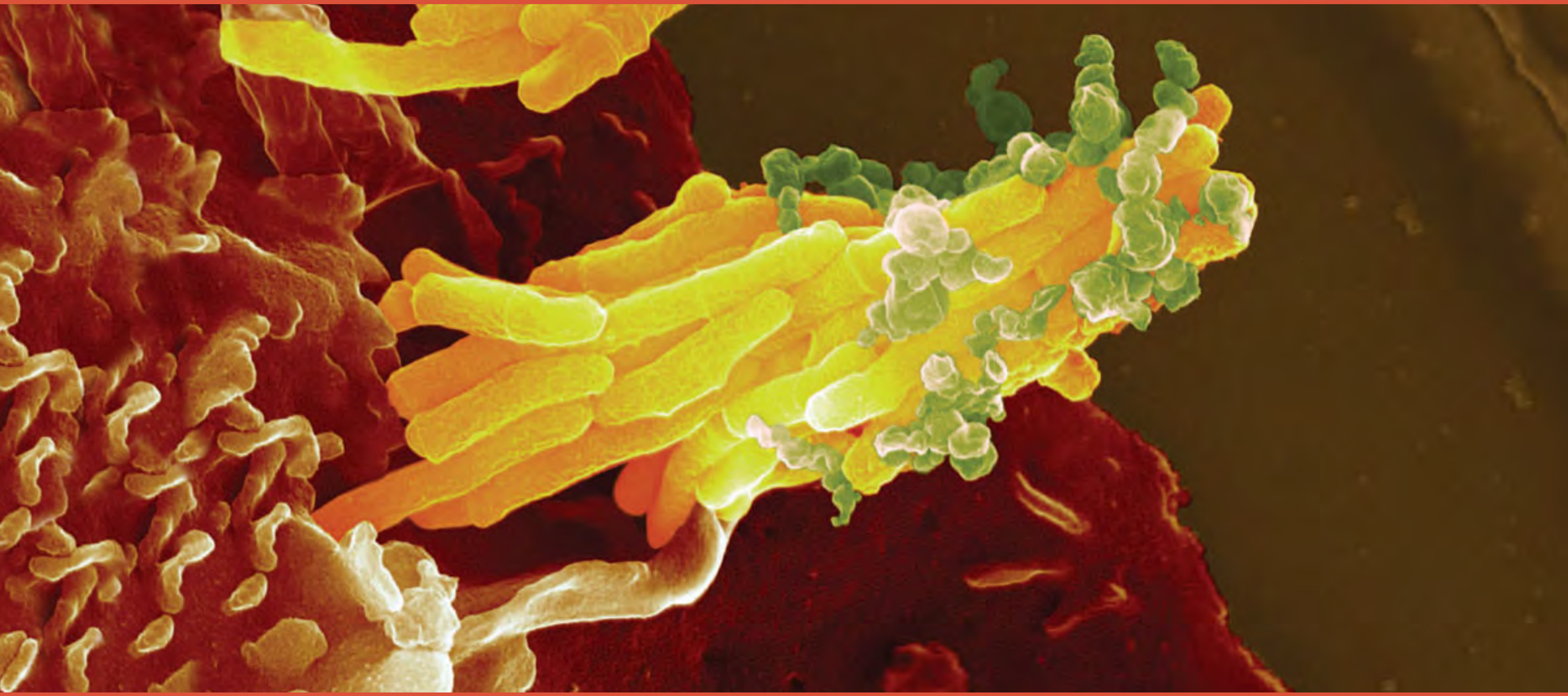
Made-to-Order Babies

Genetics is also used to find out which genes a baby will have. If the mother and the father have a defective gene, they could opt for preimplantation genetic diagnosis to make sure that the baby will be born healthy. This controversial method can determine if the embryo will be a boy or a girl, and it also prevents hereditary health risks. In preimplantation, the mother takes a drug to produce eggs, which are then fertilized with a sperm from the father. Later a DNA test is done on the embryos' cells, and then two or three healthy embryos are selected and implanted in the mother's uterus.

Microlife

TUBERCULOSIS BACTERIA
Image of the bacteria *Mycobacterium tuberculosis* (in yellow) infecting a blood cell

BACTERIA 48-49
MINUSCULE LIFE 50-51
FUNGI 52-53
BAD COMPANY 54-55
LIFE AND PROTECTION 56-57



What is a bacterium? What is a virus? How do antibiotics act on them? What function do the red and white blood cells perform when they are in action? Did you know that white blood cells are bigger than the red ones and that, by changing shape, they can pass through capillary walls to reach different tissues and hunt down foreign organisms that are in the way, such as bacteria or cancer cells? In this chapter, we will also show you how platelets, another defense system of the body, prevent hemorrhages, or bleeding. While learning about our internal functions, you will be surprised and captivated by illustrations and much more. ●

Bacteria

Bacteria are the smallest, most abundant, and hardiest life-forms on Earth. They are so microscopic that 0.06 cubic inch (1 ml) of saliva may contain up to 40 million bacterial cells. They exist and live everywhere, from our skin to the smallest cracks in rocks. Most are benign and even vital to the survival of other living beings, but some are pathogenic and can cause diseases, some of them deadly. Almost all nourish themselves by absorbing substances from their surroundings, but some make use of the energy of the sun, and others use the chemical energy in volcanic emissions. All are made up of one cell and usually reproduce by dividing in two. ●

What Are Bacteria?

Bacteria have the capacity to survive in extremely hostile environments, even at temperatures of 480° F (250° C). For this reason, they are the most ancient living organisms on the planet. In a common habitat, such as the human mouth, there can be as many as 25 different species of bacilli among the 40 million bacterial cells in just 0.06 cubic inch (1 ml) of saliva. And, if there are so many in just a small amount of saliva, imagine how many there might be in the entire world—millions and millions of species. However, only 1 percent of bacteria produce diseases. Likewise, 70 percent of antibiotics are produced through bacterial fermentation.

CLASSIFICATION OF BACTERIA

Some 10,000 bacteria species have been identified, and it is estimated that there are still many left to be discovered. They are classified both by their shape and through chemical tests to help identify specific species.

A COCCUS
Spherical cocci can live isolated, and others can group into pairs, chains, or branches.

B BACILLUS
Many bacteria have this rod-shaped form.

C VIBRIO
These bacteria have the shape of a comma or boomerang.

D SPIRILLA
This class of bacteria has a corkscrew shape.

Benign

Almost all bacteria are benign and even healthy for living beings. *Lactobacillus acidophilus*, for example, is a bacterium that transforms lactose into lactic acid to produce yogurt, and it is also present in the human body in the vagina and in the intestinal tract. The bacterium *Rhizobium*, on the other hand, allows roots of legume plants to absorb nitrogen from the soil.

Harmful

Harmful bacteria are pathogenic and are present in all living beings and in agricultural products. They can transfer from food to people, from people to food, or among people or foodstuffs. In the 14th century, the *Yersinia pestis* bacterium, present in rats and fleas, caused many deaths in what was known as the plague.

70% **OF ANTIBIOTICS** are produced from bacterial fermentation.

Parts of a Bacterium

Bacteria are usually considered the most primitive type of cell there is, because their structure is simpler than most others. Many are immobile, but others have flagella (thin hairs that move like whips to propel the bacteria in liquid media). The cell wall is generally made up of carbohydrates, including murein, a peptidoglycan complex, lipids, and amino acids. No organelles or protoplasmic formations are found in their cytoplasm.

FIMBRIAE
are used to attach to other bacteria or the cells of other living beings.

PLASMA MEMBRANE
The laminar structure that surrounds the cytoplasm of all cells like bacteria

FLAGELLA
can be fingerlike projections.

RIBOSOMES
Organelles without membranes that produce proteins. They exist in all cells. Their function is to assemble proteins based on the genetic information from the DNA that arrives in the form of messenger RNA.

PLASMID

CIRCULAR CHROMOSOME
DNA molecule closed at its ends

CELL MEMBRANE
is involved in the transport of substances and contains elements that can be toxic when they come in contact with other beings.

CELL WALL
keeps the cell from exploding if it absorbs too much water. The flagella are attached to it.

PLASMA MEMBRANE
lets certain substances into the cell while impeding the entrance of others.

FLAGELLA
Bacteria use the flagella to move. Along the length of the flagellum, there is a single row of tiny hairs. The hairs provide greater support for the flagellum in water.

ANTIBIOTIC ACTION

Certain microorganisms—fungi or bacteria—produce chemical substances that are toxic for some specific bacteria; they cause their death or stop their growth or reproduction. Penicillin and streptomycin are examples. These substances are called antibiotics.

1 When a bacterium breaks through the body's barriers, the immune system recognizes it as an antigen and generates antibodies against it.

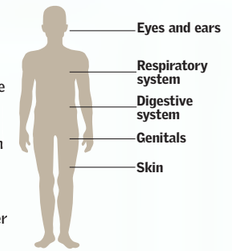
2 The leukocytes release cytokines, substances that attract more leukocytes, and by means of antibodies, they attach to the bacterium to destroy it.

3 Once the leukocytes are attached to the bacterium, they eat it.

40
MILLION BACTERIAL CELLS exist in only 0.06 cubic inch (1 ml) of saliva.

WHERE THEY ENTER

Bacteria have various established pathways to the interior of the human body: the eyes and ears; the respiratory system, through the nose and mouth; the digestive system, in food and water; the genitals and anus; and the skin, the most exposed pathway, although the bacteria can enter only through wounds.



Minuscule Life

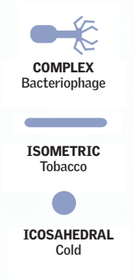
Viruses are not, in a strict sense, life-forms. They cannot live independently and are at the limit of inert material. They lack systems to obtain and store energy and to synthesize protein. For this reason, they are symbiotes committed to the cells, both prokaryotes and eukaryotes, on which they depend for their reproduction. Their structure might be nothing more than a simple envelope of protein that surrounds a package of nucleic acid (DNA or just RNA). In the case of bacteriophages, they invade bacteria and inoculate their own DNA into them. New viruses are produced from the copy of the genetic material.

"Filterable Viruses"

In 1898, while the origin of certain plant diseases was being studied, Dutch microbiologist Martinus Beijerinck discovered that some infections persisted even when filters for all known bacteria were used. He deduced that the responsible agents must be much smaller than bacteria. He called them "filterable virus," a word from the Latin related to "poison." They are so small that they cannot be seen with an optical microscope. Today we know that their structure does not even support the organelles of a cell: they are just chemical packages inserted in a protein coat.

ORNATE SHAPES

The shape of a virus has a close relationship to the chemical composition of its envelope. The proteins that compose it are expressed in the form of crystals, which take on geometric shapes, primarily simple and complex polyhedrons.



Anatomy of a Bacteriophage

This very small virus attacks bacteria exclusively. It has a capsid that contains the strand of DNA that is injected into the bacteria through a hollow tail body that has six fibers; these fibers allow it to attach to the cell wall.

NOTORIOUS FAMILIES

WITH RNA. These virus families do not have DNA in their genetic material.

FILOVIRUSES
One is the Ebola virus, which causes a type of hemorrhagic fever.

RETROVIRUSES
The best known is HIV, which produces AIDS. The HTLV retrovirus can cause leukemia.

CORONAVIRUSES
cause diseases that range from the common cold to SARS and atypical pneumonia.

FLAVIVIRUSES
Very numerous, they cause hepatitis, West Nile fever, encephalitis, and dengue.

WITH DNA. Further divided into simple-strand and double-strand viruses.

HEPADNAVIRUSES
Only the hepatitis B and D viruses belong to this family.

HERPESVIRUSES
The cause of chicken pox and herpes zoster, among others.

POXVIRUSES
In this group is the virus that causes smallpox.

PAPILLOMAVIRUSES
produce warts and are associated with cervical cancer.

Invaded Bacterium

When they reach the cell wall of a bacterium, bacteriophage viruses suddenly abandon their inert appearance: they attach to the surface of the live cell and inject their DNA, which allows the virus to make copies of itself. The life of the bacteria is altered by the takeover of the viral DNA, which gives instructions to manufacture different parts of new viruses. When the attacked cell dies, its remains are used by other nearby bacteria.

1 Adrift

The virus does not have locomotion. As an inert object, it is transported by water and air. When it finds a live bacterium, it becomes activated and attaches itself to the cell wall by means of six fibers on its tail.

30 minutes is how long the virus takes to destroy a bacterium at normal room temperature.

Attachment

Through its fibers, the virus adheres to the wall of the bacterium.

2 The Attack

When the virus reaches the wall of a live cell, it releases an enzyme that begins to dissolve the wall. A small hole is thus opened in the wall of the bacterium, through which the virus directly injects its DNA.

200 copies of the virus come out of a cell attacked and destroyed by a bacteriophage.

3 DNA Is Reproduced

The bacterium has already been invaded, and the viral DNA reprograms it. The normal activity in the bacterium stops, and it begins to build the separate parts that will form new viruses (mostly viral DNA).

GENETIC MATERIAL La The virus makes copies of itself by using the DNA molecule injected into the bacterium. Although the bacterium displays a normal external appearance, there are more than 100 copies of the virus being replicated inside.

4 Integral Production

The viral DNA that has been replicated provides instructions to the bacterium for the correct and automatic formation of the different parts of the new viruses. Once they are produced separately, the only thing left is the final assembly and proliferation of the virus copies.

5 Assembly

New capsids, tail bodies, and fibers are joined to create new bacteriophages. Once they are formed, the new viruses must wait for the break down of the bacterial wall in order to be released and attack other bacteria.

CAPSID

TAIL BODY

FIBERS

NEW VIRUS
With the tail body joined to the capsid

6 The End of the Bacterium

The viral DNA causes the bacterium to produce a substance called lysozyme. This enzyme provokes the destruction and death of the bacterium because it digests the cell wall from the inside. When the bacterium disintegrates, the new viruses disperse. They are ready to attack again.

RECYCLING. After its cell wall disintegrates, the dead bacterium leaves remains that are taken up by neighboring bacteria.

EXTERNAL VIEW OF THE BACTERIA

CAPSID
contains a strand of DNA that is unloaded into the interior of the bacteria when the virus attaches to it.

DNA
contains all the information necessary for the virus to replicate.

FIBERS
help the virus attach to the surface of the cell that it attacks.

CAPSID
A hollow tube with the ability to contract and inject viral DNA into a bacterium

Fungi

Fungi are living beings from the Fungi kingdom that are similar to plants, but they do not have the ability to synthesize their own food; this forces many of them to be parasites of other vegetables or animals and, of course, humans. Multicellular fungi tend to be formed by filaments and spores that reproduce very easily; others are unicellular. Infections by fungi (mycosis) tend to be superficial, such as ringworm or athlete's foot, caused by dermatophytes, but they can be systemic if, for example, they colonize the blood.

0.00020 inch (5 microns)

SPORES LARGER THAN THIS SIZE TEND TO CAUSE SURFACE REACTIONS BECAUSE OF THEIR DIFFICULTY IN PENETRATING THE SKIN. THAT IS WHY THE SPECIES IN *ALTERNARIA, CLADOSPORIUM, ASPERGILLUS,* AND *PENICILLIUM* COMMONLY PRODUCE ALLERGIES.

Parasitic Cells

Not all fungi cause disease. Many, which are essentially saprophytes, have a beneficial purpose. They grow on organic matter that they decompose through exoenzymes, and then they absorb and recycle it. By not being able to carry out photosynthesis, their ability to obtain energy and biosynthesis depends on the organic material they absorb.

Penicillium

This microscopic fungus, very common in the domestic environment, is used in the production of blue cheeses and is the base for the first antibiotic created by man: penicillin. Its antibiotic properties were discovered by accident.

SPORANGIA
The spherical sacs that contain the reproductive cells (spores). Because these are small and asexual, they are called conidia. As happens with all multicellular fungi of the deuteromycota type, the sporangia mature and break, releasing the conidia.

CONIDIOPHORES
The branches of the stalk that have conidia on one of their ends and which together make up the reproductive organ of the fungus.

0.7 ounce (20 g)

The amount of penicillin that can be obtained for each quart (about 1 l) of culture of the *Penicillium chrysogenum* fungus with current biotechnological methods. Penicillin alters the cell wall of bacteria and destroys them.

Getting Rid of Fungi

Fungal infections respond to a variety of drug treatments. More superficial infections, such as oral candidiasis, respond to the local application of antimycotic substances. Deeper systemic infections, however, particularly in persons with some sort of immune system deficiency, can be more difficult to cure. Sometimes they require prolonged administration (as long as several months) of drugs that are taken orally and act systemically (throughout the entire body). These drugs frequently have a level of toxicity that must be taken into account when evaluating the advantages and disadvantages of each treatment.

1 THE CELL
Mycotic cells, which on their own are harder to treat than bacteria, look a lot like human cells. The drugs used must be sufficiently selective to attack only these cells and not human cells.

Antifungal drug

Cellular wall

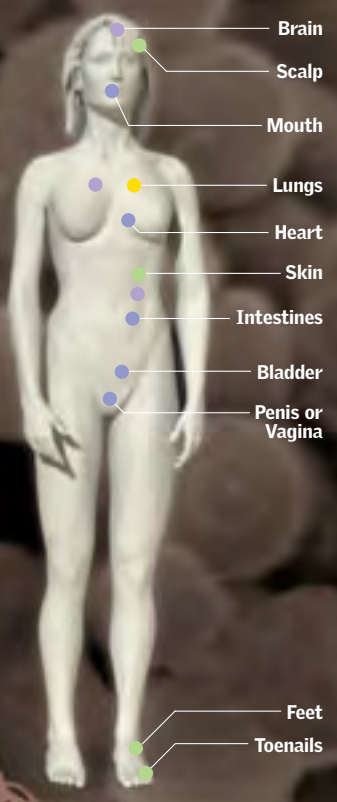
2 THE DRUG
The main action of antimycotic drugs is to damage the envelope of the mycotic cell, which makes up 90 percent of its mass. This way, the cytoplasm is left without support and dissolves in the bloodstream.

ALMOST WITHOUT DIFFERENCE
The cells that make up the different parts of a fungus are not very different from each other. Each has a polysaccharide wall that does not alter its permeability.

HYPHA
The hyphae are the filaments that make up the body of a multicellular fungus. Generally they form a networked structure (mycelium). The portion of the hypha that rises to branch off and form conidiophores is called the stalk. The fungus is the ensemble of all the hyphae and can have many stalks.

WHERE THEY COMMONLY INVADE

Fungi are very simple organisms. In human tissues, some species generate superficial wounds (in the toenails or fingernails, skin, or mucous membranes) or even fatal infections in some internal organs.



CRYPTOCOCCOSIS
This infection can cause certain forms of meningitis (inflammation of the meninges, the membranes that cover the brain) and pneumonias (lung infections). It can also affect the skin and the bones.

ASPERGILLOSIS
Aspergillus fumigatus is a fungus that tends to spread through air-conditioning systems. It attacks the lungs of persons with a suppressed immune system.

DERMATOPHYTOSIS
This fungal infection is the most common superficial mycotic infection and can affect toenails or fingernails (onychomycosis), the feet (athlete's foot), and the scalp (ringworm). Ringworm can cause hair loss.

CANDIDIASIS
Candida species prefer mucous membranes, so they attack such areas as the mouth or vagina. Alteration of the natural flora of the vagina can lead to this type of infection, and more than half of all women have suffered from such an infection at some time.

Bad Company

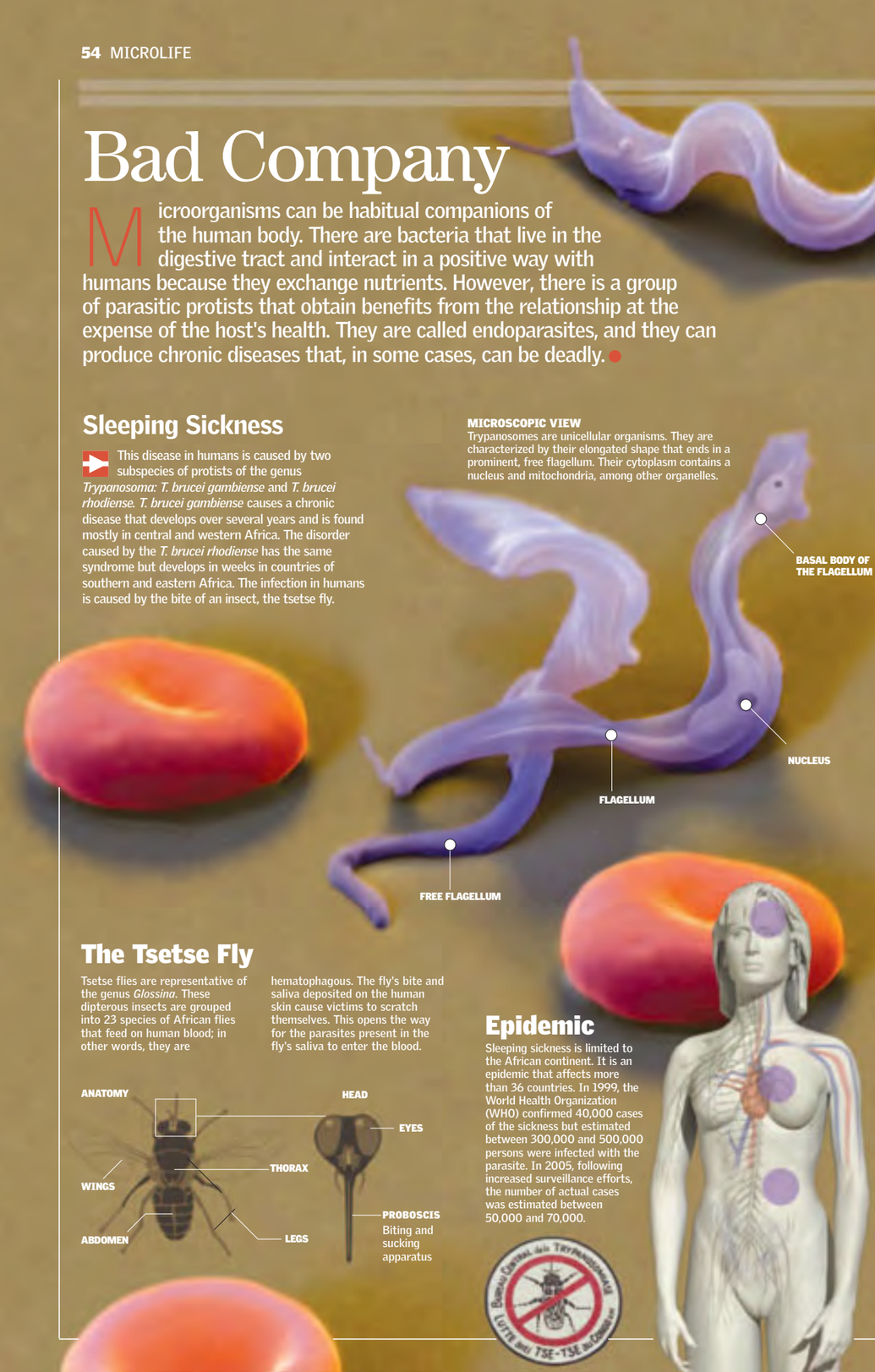
Microorganisms can be habitual companions of the human body. There are bacteria that live in the digestive tract and interact in a positive way with humans because they exchange nutrients. However, there is a group of parasitic protists that obtain benefits from the relationship at the expense of the host's health. They are called endoparasites, and they can produce chronic diseases that, in some cases, can be deadly.

Deadly Nightmare

Trypanosoma brucei gambiense, the tsetse fly, and the human body are the three players in this disease. The fly sucks human blood, which already contains the parasites. The parasites undergo a series of transformations inside the body of the fly and finally lodge themselves in its salivary glands. When the fly with parasites in its saliva searches for food and bites a person, it transfers the trypanosomes. The first phase of the sickness, similar to other diseases, includes itching, fever, headaches, and joint pain. Later the endoparasite crosses the hematoencephalic barrier and attacks the central nervous system. There it disrupts vital neurological processes—including the waking and sleeping cycle—which causes drowsiness and even death.

Sleeping Sickness

This disease in humans is caused by two subspecies of protists of the genus *Trypanosoma: T. brucei gambiense* and *T. brucei rhodiense. T. brucei gambiense* causes a chronic disease that develops over several years and is found mostly in central and western Africa. The disorder caused by the *T. brucei rhodiense* has the same syndrome but develops in weeks in countries of southern and eastern Africa. The infection in humans is caused by the bite of an insect, the tsetse fly.



TRYPANOSOMA BRUCEI

Location	**Africa**
Size	**0.001 inch** (30 microns)
Disease	**Sleeping Sickness**

DISTRIBUTION

The tsetse fly, which transmits the trypanosome, is found in Africa between 15° N and 20° S. More than 60 million people are potential victims of sleeping sickness in this region.

The Tsetse Fly

Tsetse flies are representative of the genus *Glossina*. These dipterous insects are grouped into 23 species of African flies that feed on human blood; in other words, they are hematophagous. The fly's bite and saliva deposited on the human skin cause victims to scratch themselves. This opens the way for the parasites present in the fly's saliva to enter the blood.

Epidemic

Sleeping sickness is limited to the African continent. It is an epidemic that affects more than 36 countries. In 1999, the World Health Organization (WHO) confirmed 40,000 cases of the sickness but estimated between 300,000 and 500,000 persons were infected with the parasite. In 2005, following increased surveillance efforts, the number of actual cases was estimated between 50,000 and 70,000.

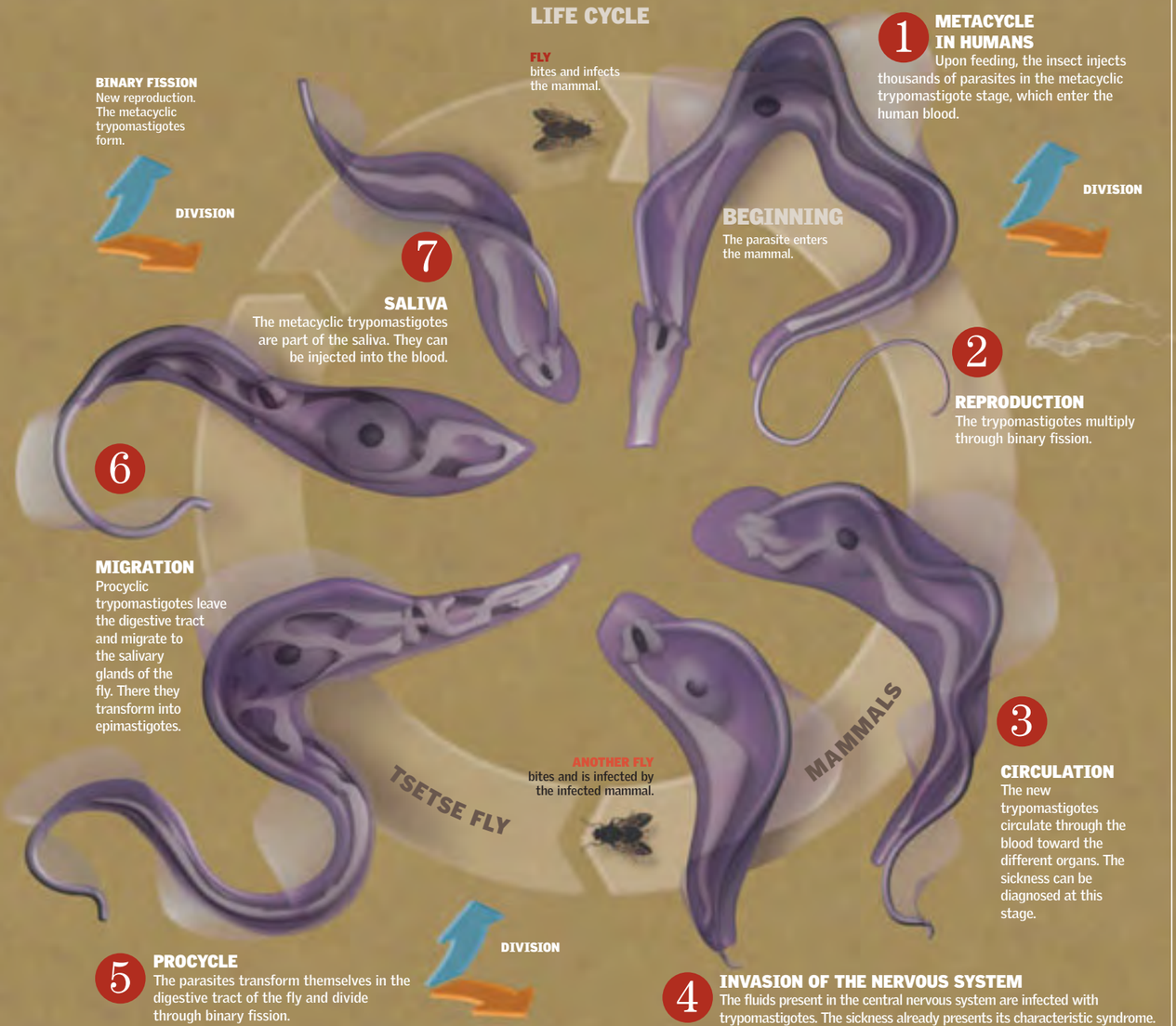
THE DISEASE, STEP BY STEP

1 FIRST SYMPTOMS
The small wounds in the skin allow the parasite to enter into the blood.

2 SLEEPINESS
Through blood circulation, the trypanosome lodges in different organs of the human body.

3 SERIOUS ILLNESS
The endoparasite reproduces in bodily fluids, such as blood, lymph, and cerebrospinal liquid.

LIFE CYCLE



Life and Protection

White and red blood cells are the main cellular components of blood, and they play important roles in the body. The red blood cells transport oxygen from the lungs to the tissues, and they carry carbon dioxide on their return. They live for about 120 days and then die in the spleen. The white blood cells have a smaller presence than the red ones, but they are in charge of protecting against infections, and they roam the body looking for viruses and bacteria.

PSEUDOPODIUM
serves as a locomotive device for certain protozoa and leukocytes.

Hunter

The white blood cell detects the presence of organisms harmful to the body and traps them. The invaders are engulfed and destroyed.

White Blood Cells

These cells occur mainly in the blood and circulate through it to fight infections or foreign bodies, but they can occasionally attack the normal tissues of their own body. They are part of the human body's immune defense. For each white blood cell in the blood, there are 700 red blood cells. White blood cells, however, are larger. Unlike the red ones, they have a nucleus. By changing shape, they can go through capillary walls to reach tissues and hunt their prey.

ANATOMY OF A WHITE BLOOD CELL

In a drop of blood, there can be about 375,000 white blood cells with different shapes and functions. They are divided into two groups: the granulocytes, which have granules in the cytoplasm, and the agranulocytes, which do not and which include the lymphocytes and the monocytes. Monocytes engulf the invader, ingest it, and then digest it.

1 White blood cells can come out of blood vessels and move between the tissues. When they detect an intruder, they approach to hunt it down.

2 The cell stretches, forming a pseudopodium, or false leg, which pushes against the medium, and it then propels the rest of the cell to advance toward the bacterium.

3 It traps the bacterium and destroys it. During the fight against the infection, millions of white blood cells may die and appear as pus.

Red Blood Cells

The main carriers of oxygen to the cells and tissues of the body, red blood cells make up 99 percent of the cells in the blood. The have a biconcave shape so that they have a larger surface for oxygen exchange in the tissues. In addition, they have a flexible membrane that allows the red blood cells to go through the smallest blood vessels, obtain oxygen from the lungs, and discharge it in the tissues. The cells do not have a nucleus.

ANATOMY OF A RED BLOOD CELL

The cell has the shape of a flattened disk that is depressed in the center. This shape gives it a large surface in relation to its volume. In this way, the hemoglobin molecules that transport oxygen are never far from the cell membrane, which helps them pick up and deposit oxygen.

HEMOGLOBIN
Formed by a heme group (with iron, which will give blood its red color) and globin, a globular protein

OXYHEMOGLOBIN
Formed when the hemoglobin takes up oxygen and gives blood its colorsangre.

Platelets

These small cells are key to stopping any bleeding. They intervene in blood clotting and form a platelet plug. If a blood vessel is cut and the endothelium is affected, the platelets modify their structure and join the injured tissue to form the plug.

1 Platelets accumulate and form a plug in the wound.

2 The red blood cells close in. Together with a protein network they form the blood clot. The white blood cells fight the infection.

200,000
red blood cells are produced daily by a human being.

0.0003 inch
(7-8 MICROMETERS)
The average diameter of a red blood cell. However, the cell is flexible and can change shape.

The Most Common Diseases

POLLEN
An enlarged photo of the pollen of Timothy grass (*Phleum pratense*), one of the most allergenic and best-known grasses because it causes hay fever

CANCER 60-61
NEUROLOGICAL PROBLEMS 62-63
BONE DEGENERATION 64-65
CIRCULATORY CONDITIONS 66-67
RESPIRATORY INFECTIONS 68-69
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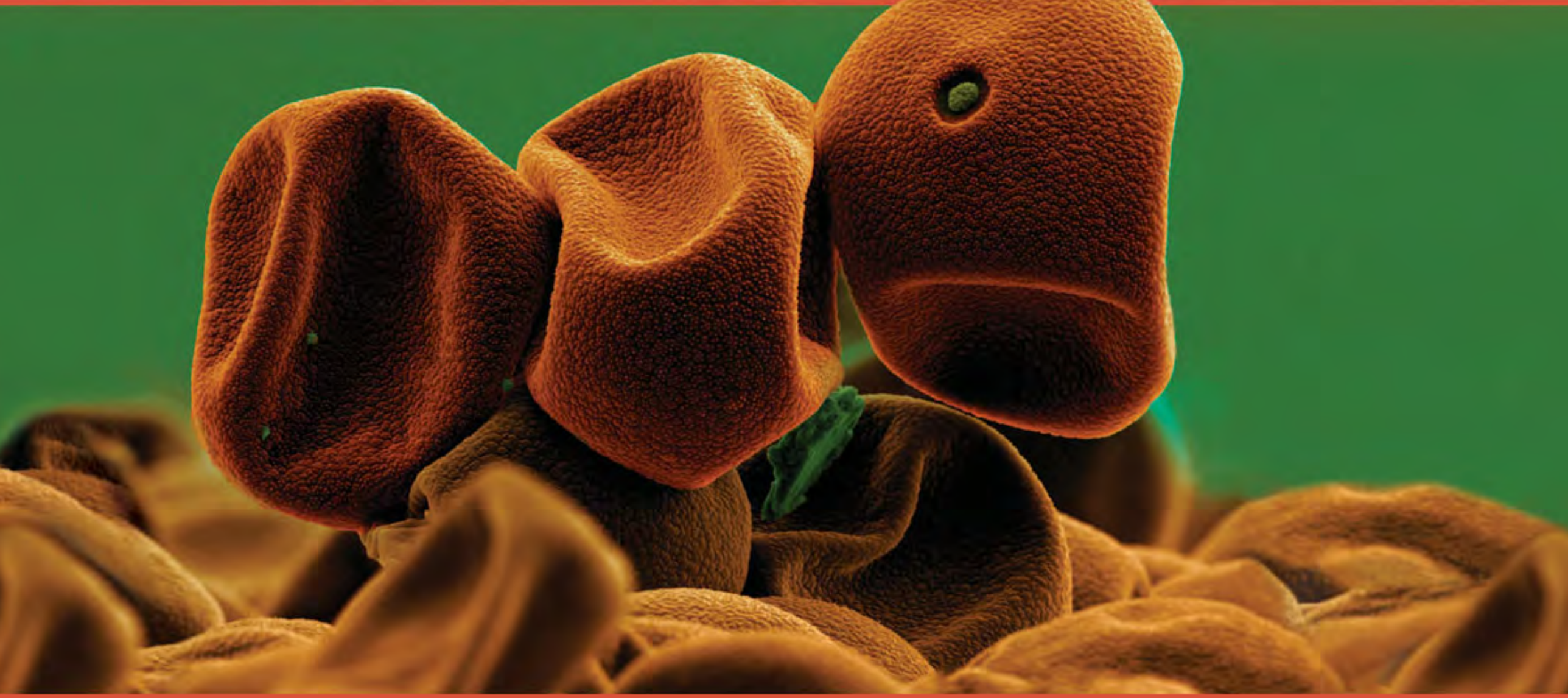


Allergies are the body's response to a foreign substance, called an allergen. The most common are pollen, mites, animal dander, and nut proteins. In this chapter, we tell you which are the most common diseases that humankind suffers from today—some of them worse than others—their symptoms, and how they can be avoided. The information, written in an accessible and understandable way, is accompanied by pictures and full-color images that reveal, for example, how metastasis happens and how the AIDS virus attacks.

Turn the page and you will discover unknown and astounding aspects of human disease. ●

Cancer

The word "cancer" describes a group of more than 200 diseases caused by uncontrolled cell division. The genes of normal cells change so that regular cell death (apoptosis) does not take place, and the tissues grow much larger than normal. Some factors, such as tobacco use and excessive exposure to different types of radiation, can notably increase the chances of developing cancer. In other cases, the genes that alter the normal functions of cells can be inherited.

How It Behaves

In general, cancer consists of the abnormal growth of cells. When the cells of a tissue undergo disorderly and accelerated cell division, they can invade other, healthy tissues in the body and often destroy them. Instead of undergoing a controlled and programmed cell death (apoptosis), cancer cells continue proliferating. They can form a lump or bulge in an organ, called a tumor. Tumors are called malignant if they are formed by cancer cells; otherwise they are called benign.

Common Symptoms

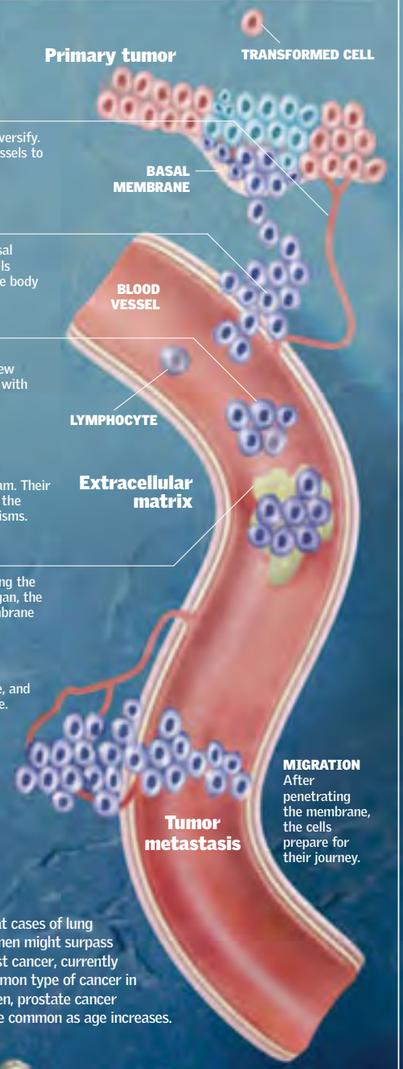
Although they are not always indicators of cancer, unusual bleeding, unexplained changes in weight, indigestion, and difficulty swallowing can be signs of tumors.

Metastasis

Metastasis occurs when cancer cells pass from their original proliferation site to another that they were not in direct contact with (e.g., from the lungs to the brain). To achieve this migration, the cells build their own circulatory and feeding systems. This allows them to penetrate the blood vessels (intravasation) and survive after extravasation. Only one in every 1,000 cells can survive the complex intermediate processes, but if metastasis does occur, it is almost irreversible and causes irreparable damage.

CHAOTIC DIVISION
Through a genetic alteration of mitosis, the cells divide rapidly and indefinitely.

METASTASIS: STEP BY STEP



1 **ANGIOGENESIS**
The cancer cells divide and diversify. They form their own blood vessels to receive nutrients and oxygen.

2 **INTRAVASATION**
After passing through the basal membrane, the metastatic cells invade the blood vessels of the body and enter the bloodstream.

3 **MIGRATION**
The cells travel through the bloodstream and move to a new organ, different from the one with the original tumor.

4 **INTERACTION**
Cancer cells interact with the lymphocytes in the bloodstream. Their adhesion to platelets leads to the formation of tumorous embolisms.

5 **INVASION**
Before migrating and producing the secondary tumor in a new organ, the cells adhere to the basal membrane of the blood vessels.

6 **EXTRAVASATION**
The cells break the membrane, and the final migration takes place. They deposit themselves in metastatic form and begin angiogenesis to arrange for a capillary system that can provide them with nutrients. From there, they begin their growth.

MIGRATION
After penetrating the membrane, the cells prepare for their journey.

Phases of Cancer

Before the definitive formation of cancer, there are two prior noncancerous stages: hyperplasia and dysplasia. The cell volume increases as the cells undergo uncontrolled cell division. The proliferation can be detected through studies done under a microscope (biopsies).

1 **HYPERPLASIA**
Although the cell structure remains normal, the tissue increases in size. Hyperplasia is reversible.

2 **DYSPLASIA**
The tissue loses its normal appearance. Like hyperplasia, this stage can be detected with microscopic tests.

3 **CÁNCER**
The cells grow uncontrollably and settle in one place. If they migrate and spread to other parts of the body, it is called metastasis.

Breast Cancer

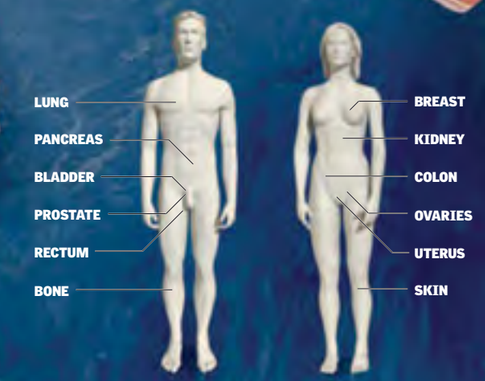
One in nine women develops this disease, which causes the most deaths among women. The risk of breast cancer increases with age. The most common symptom is the appearance of a small lump in the breast, which can be removed early with surgery. Other symptoms of cancer are the appearance of blood in the nipple and dimples in the breast skin. A mammogram is usually used to detect cancer. If the results of this study are positive, then treatment can begin early.

CANCER CELLS
An agglomeration of cancer cells exhibits a protein nucleus (green) and the Golgi apparatus (pink).

TUMORS
are produced when the cancer cells group and form agglomerates. Tumors can be benign (noncancerous) or malignant.

Most Frequent Cancers

The most common cancer is lung cancer. Because of the large smoking population, the incidence of this cancer remains high. In recent years, the frequency of lung cancer in women has increased, and it is possible that cases of lung cancer in women might surpass those of breast cancer, currently the most common type of cancer in women. In men, prostate cancer becomes more common as age increases.



Neurological Problems

Diseases that directly affect the brain cause structural, biochemical, or electrical changes in the brain or the spinal cord. When some of these diseases (Alzheimer's, Parkinson's, multiple sclerosis) affect the body, different symptoms appear, such as memory and reasoning disorders, tremors, rigidity of movements, paralysis, or loss of sensation. The challenge for science is to discover a way to reverse them. So far, the symptoms can only be reduced.

Alzheimer's Disease

Alzheimer's disease, which has no cure, affects mostly persons over 60 years of age. Age and the aging process are determining factors. The cortex of the brain suffers atrophy, which is permanent because nerve cells cannot regenerate. In a brain affected by Alzheimer's, the abnormal deposit of amyloid protein forms neuritic (senile) plaques in the brain tissue. Tangles of degeneration (neurofibrillary tangles) form, which progressively damage the brain's functioning.

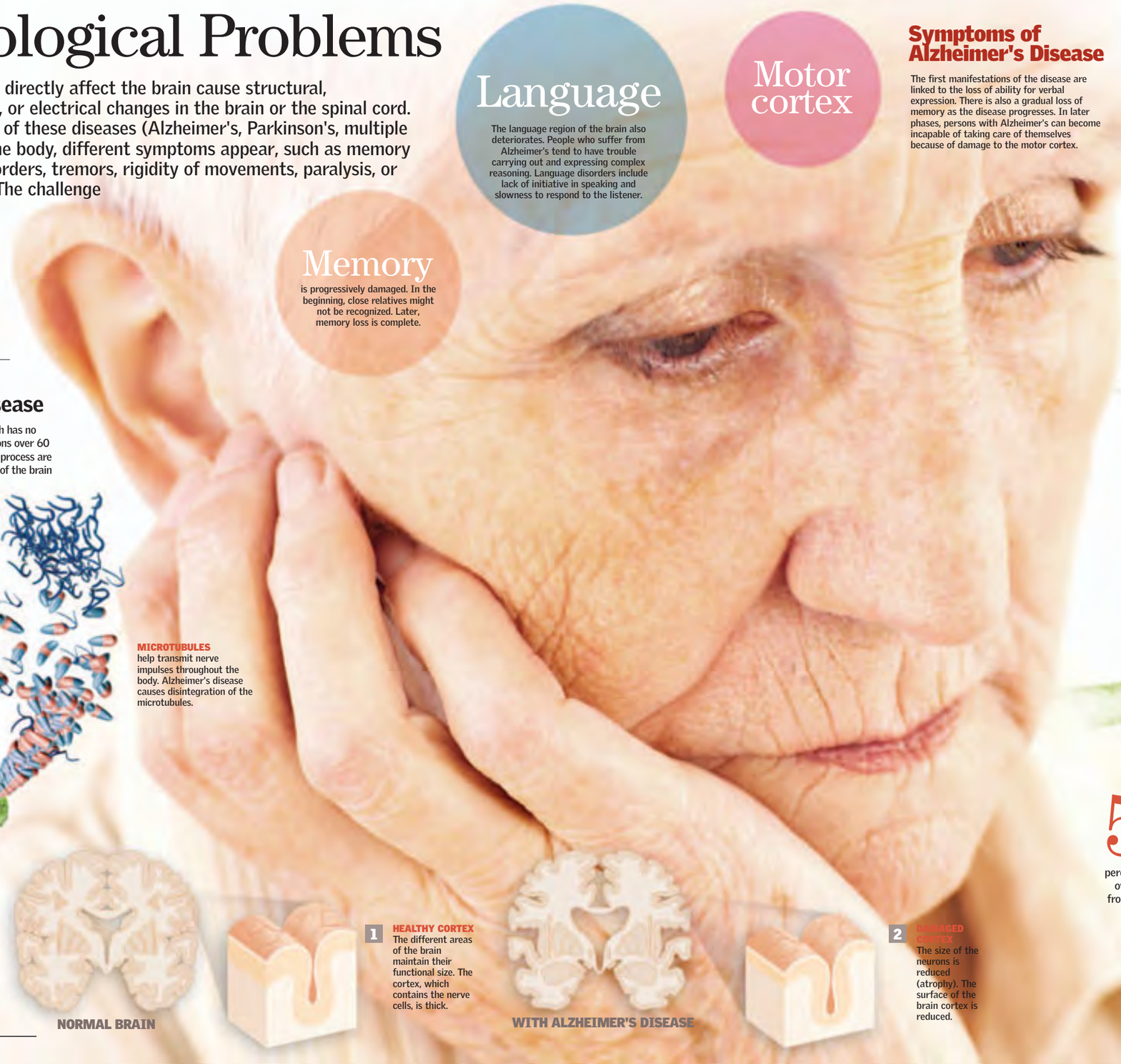
Neurons

Alzheimer's disease causes the appearance of senile plaques and tangles of degeneration that damage the neurons.

MICROTUBULES
help transmit nerve impulses throughout the body. Alzheimer's disease causes disintegration of the microtubules.

Deterioration

As the disease progresses, the brain loses volume, and the sections of the cortex that carry out different processes are progressively damaged. The areas of the cortex shrink.



Symptoms of Alzheimer's Disease

The first manifestations of the disease are linked to the loss of ability for verbal expression. There is also a gradual loss of memory as the disease progresses. In later phases, persons with Alzheimer's can become incapable of taking care of themselves because of damage to the motor cortex.

Parkinson's Disease

Parkinson's disease is a degenerative disease that attacks one in 200 persons, mostly over 60 years of age. This neurological disorder, which affects more men than women, progressively deteriorates the central nervous system. The cause of the disease is unknown. Its appearance is related to the reduction of dopamine in certain brain structures. Among the main noticeable effects are tremors, muscle rigidity, and a slowing of body movements. Parkinson's also causes complications in speech, walking, and carrying out daily chores. Progressively tremors in the arms and legs occur, followed by facial inexpressiveness and repetition of movements.

EXPRESSIONS
Persons affected by Parkinson's disease tend to suffer from rigidity in their facial expressions.

ELECTRICAL CONDUCTION
occurs inside each neuron, preceding the interneural synapse. In Parkinson's disease, the connections and their ability to function are reduced dramatically.

DOPAMINE
Produced by the substantia nigra in the brain and transported by the nerve fibers, one function of this neurotransmitter is to influence the body's movements. The basal ganglia (deep inside the brain) receive reduced levels of dopamine. The execution of regular movements becomes altered.

SYMPTOMS
Muscle rigidity and slowing movement. Body posture is characterized by a forward bending of the head and trunk.

Multiple Sclerosis

A common neurological disorder that appears sometime between the ages of 20 and 40, it can cause distorted or double vision, paralysis of the lower limbs or one-half of the body, clumsy movements, and difficulty in walking. Multiple sclerosis occurs when the immune system damages the layers of myelin that cover nerve fibers.

MYELIN LAYER
covers the nerve fibers. In multiple sclerosis, the immune system macrophages remove sections of myelin and leave the nerve fiber uncovered, which causes nerve impulses to travel slowly or not at all.

NERVE FIBER

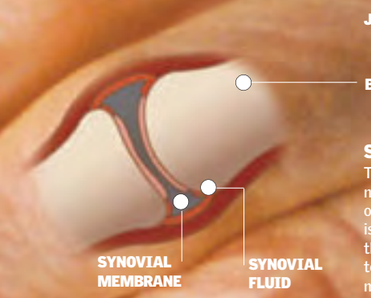
50
percent of persons over 80 suffer from neurological diseases.

Bone Degeneration

Because joints are made to function in very specific ways, any abnormal movement tends to cause injury. Some injuries can result from falling or being struck, while others can be caused by degeneration of the joint. The general term for inflammation of the joints is arthritis. In the bones, the loss of bone mass is called osteoporosis and is usually related to aging.

Osteoarthritis

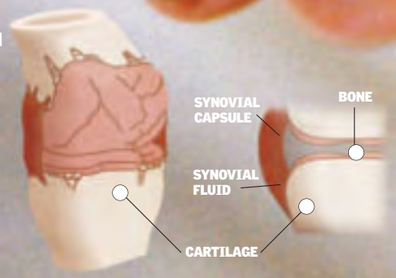
Osteoarthritis, the most common form of arthritis, is the process of progressive erosion of the joint cartilage. Unlike rheumatoid arthritis, which can affect other organs, osteoarthritis affects only the joints, either in a few specific joints or throughout the body. The joint degeneration of osteoarthritis could worsen due to congenital defects, infections, or obesity. Because cartilage normally erodes with age, osteoarthritis affects persons close to 60 years of age.



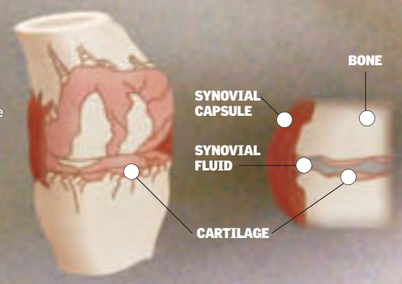
STRUCTURE
The joint is normally made up of cartilage that is lubricated by the synovial fluid to allow ease of movement.

PHASES OF THE DISEASE

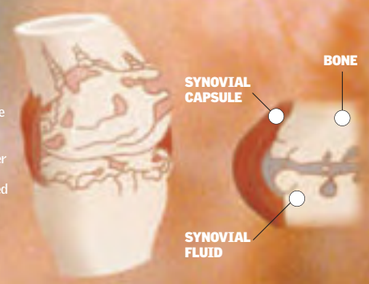
1 DETERIORATION
Osteoarthritis causes progressive damage of the cartilage. When the cartilage cells die, cracks appear on the surface of the bone. From this moment on, the synovial fluid begins to leak. Later the fluid enters the cartilage and causes it to degenerate.



2 BONE FRACTURE
The cartilage is worn away down to the bone and breaks its surface. From this erosion, a hole appears. New blood vessels begin to grow. To fill the gap, a plug develops that is made up of fibrocartilage.



3 EXPOSED BONE
The plug disappears and leaves the bone surface exposed. If the surface fractures become deeper, the synovial fluid can enter the bone marrow and form a cyst surrounded by weakened bone. Osteophytes (bone spurs) can appear.

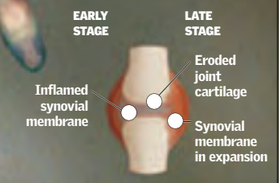


30%
or more of the mineral density of the bone is lost through the degeneration of osteoporosis.

Rheumatoid Arthritis

In this autoimmune disease, the immune system, triggered by some antigen in a predisposed person, begins to attack the body's tissues. The joints become inflamed and deformed. As rheumatoid arthritis develops over time, the tissues of the eyes, skin, heart, nerves, and lungs may be affected.

SYMPTOMS
The typical symptoms are fatigue, anorexia, and muscle and joint pain.



Symptoms of Osteoarthritis

The most common signs of the degeneration of the joint cartilage are the deformation and swelling of the joints. Some cases might include numbness and limited movement of the joint.

Gout

is caused by high levels of uric acid in the blood. The acid is deposited in the joints, causing inflammation. Primary gout is due to a congenital metabolic error, and secondary gout is caused by any other metabolic disorder.

Osteoporosis

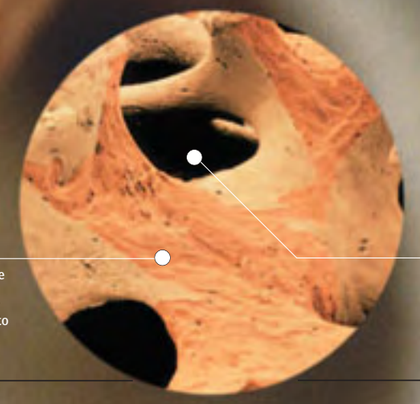
Between the fifth and sixth decade of life, the bones tend to become more porous and to decrease in thickness. Both men and women lose bone mass, even if they are healthy. The levels of estrogen decrease rapidly in women after menopause, leading to osteoporosis in many cases. In men, the reduction in testosterone is gradual, and the likelihood of suffering from osteoporosis is lower.

HEALTHY BONE
An outer membrane, the periosteum, wraps around a band of hard, cortical bone and spongy bone.

NORMAL BONE

FRAGILE BONE
As it loses bone mass, the bone's central channel widens, and cracks appear in the osteons.

WITH OSTEOPOROSIS



REDUCED MASS
Osteoporosis generates a decrease of total bone mass. As a consequence, pores appear that could weaken the bone.

SURFACE
is more susceptible to fracture as the bone loses rigidity because of injury to the bone cells.

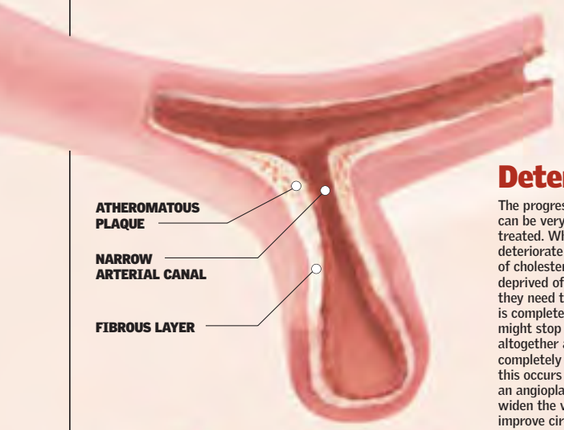
PORES
appear on the bone surface as a consequence of tissue degeneration and the progressive erosion of the bone.

Circulatory Conditions

Among the most frequent diseases that affect the circulatory system are those that result from blockages of the arteries and veins. The buildup of fat in the arteries can lead to arteriosclerosis, which blocks the supply of blood to the tissues. In many cases, as in a myocardial infarction, there are no warning signs. This could lead to the death of the tissue that loses blood supply. Certain drugs can be used to dilate blocked blood vessels.

Arteriosclerosis

Arteriosclerosis of the cardiac blood vessels, or heart disease, is caused by a narrowing of the arteries as cholesterol, cells, and other substances accumulate in the lining of these vessels. Arterial obstruction is gradual; it begins when excess fats and cholesterol build up in the blood. These substances infiltrate the lining of the arteries to create microscopic damage sites. Atheromata form, which in turn develop into fatty masses called plaque. The appearance of these plaques thickens the arterial walls and prevents the normal flow of blood, thus reducing the blood flow.



Deterioration

The progression of arteriosclerosis can be very dangerous if it is not treated. When the arteries deteriorate because of the presence of cholesterol, the organs can be deprived of the amount of blood they need to function. If the artery is completely blocked, an organ might stop receiving blood altogether and, as a consequence, completely lose its function. When this occurs in the heart, for example, an angioplasty must be done to widen the vessel once again and improve circulation in the tissue.

1 **FREE** Without the formation of fatty plaque, the blood flows normally.

2 **WITH ATHEROMATOUS PLAQUE** Inside this plaque, cholesterol and other substances accumulate.

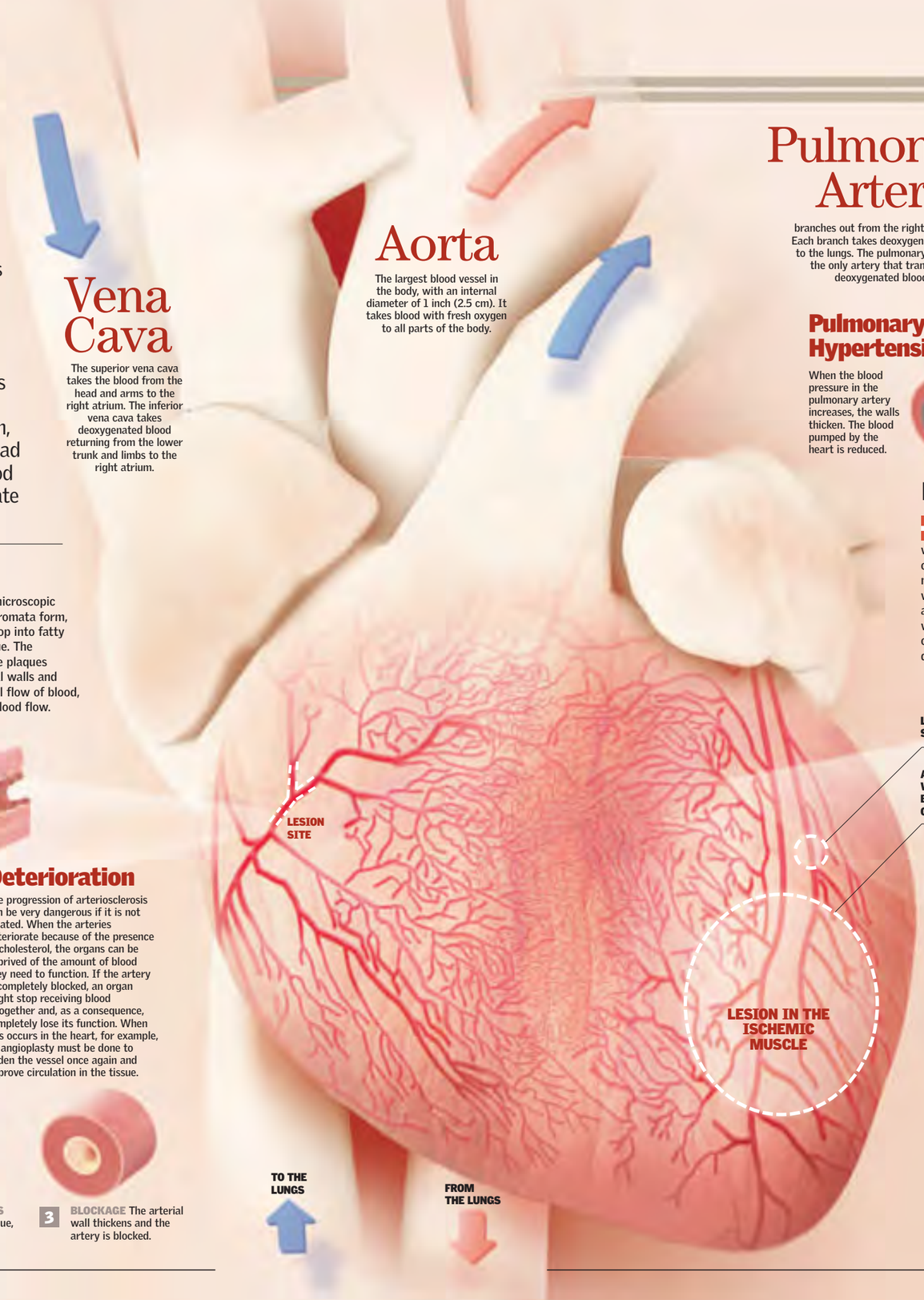
3 **BLOCKAGE** The arterial wall thickens and the artery is blocked.

Vena Cava

The superior vena cava takes the blood from the head and arms to the right atrium. The inferior vena cava takes deoxygenated blood returning from the lower trunk and limbs to the right atrium.

Aorta

The largest blood vessel in the body, with an internal diameter of 1 inch (2.5 cm). It takes blood with fresh oxygen to all parts of the body.



Pulmonary Artery

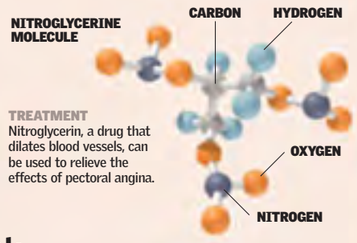
branches out from the right ventricle. Each branch takes deoxygenated blood to the lungs. The pulmonary artery is the only artery that transports deoxygenated blood.

Pulmonary Hypertension

When the blood pressure in the pulmonary artery increases, the walls thicken. The blood pumped by the heart is reduced.

Pectoral Angina

Chest pains could be a warning sign that the cardiac muscle is not receiving enough blood to keep up with the demands of the work it is doing. In pectoral angina, very strong chest pains occur because of the arteries that are obstructed by arteriosclerosis.



TREATMENT
Nitroglycerin, a drug that dilates blood vessels, can be used to relieve the effects of pectoral angina.

WIDENING VESSELS
To reestablish adequate blood flow, drugs such as nitroglycerin can be used. The narrow blood vessels dilate, and the heart does not have to work so hard.

1 **BEFORE** The narrowed blood vessels do not provide adequate blood flow to the heart.

2 **AFTER** With the drugs applied, the walls of the blood vessels relax and widen.

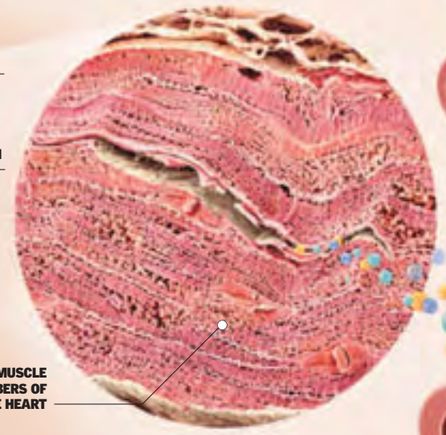
Heart Attack

An infarction usually happens suddenly, almost without warning. The pain in the chest area can be like angina but generally is more severe and does not go away with rest. A person who suffers an attack experiences excessive sweat, weakness, and, in some cases, loss of consciousness. The attack could be a direct consequence of the lack of blood volume. If the artery begins to fill with fat after the partial obstruction of a blood vessel by a plaque, a lesion in its wall may form, resulting in the formation of a thrombus that could block the blood vessel. This could deprive a portion of the myocardium of oxygen, which would then produce a heart attack.

HOW IT HAPPENS
A blockage in a coronary artery prevents blood from reaching the muscle. If the blockage is complete, the blood-deprived muscle dies.

1 **ATHEROMA** The inner wall of the artery accumulates fat, producing an atheroma.

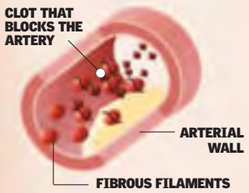
2 **INFARCTION** A clot forms. The myocardium stops receiving blood, and this region dies.



DETECTION
When a heart attack occurs, the muscle fibers release enzymes into the bloodstream.

ENZYMES make it possible to estimate the severity of the attack. If enzyme levels are high, it was severe.

THROMBUS IN THE ARTERY
forms when blood platelets come into contact with collagen in the lining of the artery. Fibrous filaments appear that interact with the platelets, and the clot grows. The artery becomes blocked.



Thrombosis

Unlike a natural clot that forms to prevent blood loss from an injured blood vessel, in arteriosclerosis, the blood vessels are already damaged. This causes a predisposition to form a thrombus when an atheroma ruptures. In thrombosis, unlike arteriosclerosis, clots form that in many cases can migrate through the bloodstream and lodge somewhere away from the original site.

Respiratory Infections

In many cases, respiratory-tract obstructions can cause severe complications. Although bronchitis is more often related to a viral or bacterial infection, the chronic form is associated with the consumption of tobacco, because the smoking habit has severe consequences for the respiratory system. In cases of pneumonia or complications associated with the respiratory tract, bacteria or other airborne microorganisms are usually responsible for the infection.

Acute Bronchitis

An inflammation of the bronchi that develops suddenly, it can result from an infection of the respiratory tract or exposure to toxins, irritants, or atmospheric pollutants. Acute bronchitis is usually caused by a virus. The common symptoms are cough, which increases the need to salivate, and in some instances a high fever. In acute bronchitis, the tissues and membranes of the bronchi become inflamed, and the air passages narrow. The amount of mucus increases, causing congestion.

HOW IT HAPPENS

The disease usually affects the large- and medium-sized bronchi. In children or older persons, the infection can expand and inflame the bronchioles and lung tissue.

Chronic Bronchitis

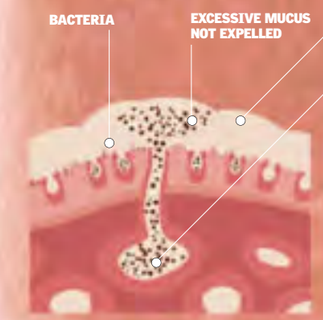
The most common cause of chronic bronchitis is the irritation of the bronchi by chemical substances. The effect of tobacco, which contains nicotine, is another primary factor in the development of chronic bronchitis. The typical symptoms are cough with phlegm, hoarseness, and difficulty breathing. One effect of smoking is an excessive production of mucus, followed by enlargement of the mucous glands and dysfunction of the cilia. Thus, the respiratory tract can be affected and can even function as a medium for the growth of some bacteria. In some cases, chronic bronchitis can be brought on by recurrent episodes of acute bronchitis.

Bronchi

The lung has two main bronchi that branch out from the trachea. These two bronchi branch out further into an intricate network of bronchial branches that provide space for the passage of air in the lungs.

Pneumonia

causes the inflammation of the smallest bronchioles and the alveolar tissue. In 1976, a bacteria was detected, *Legionella pneumophila* (pictured), that causes a severe, rapidly spreading form of pneumonia.

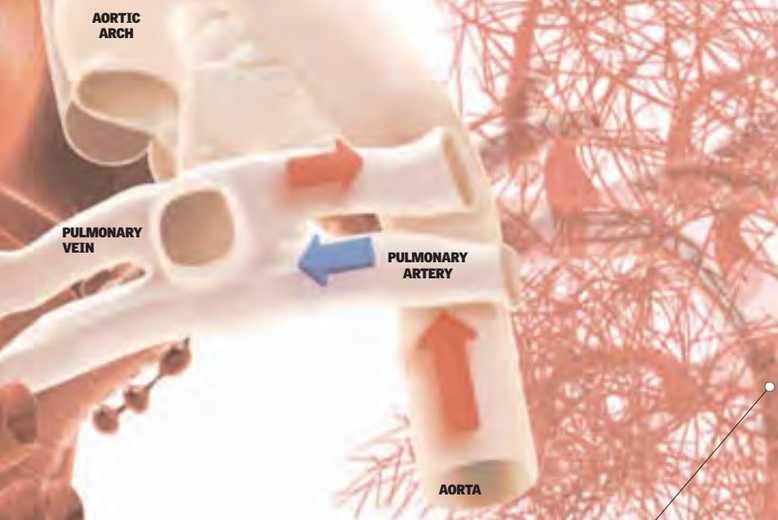


INFECTED BRONCHI

From the inhalation of irritant chemicals, the glands that secrete mucus become enlarged. This increases the production of mucus that cannot be eliminated from the respiratory tract. Serious breathing difficulties follow.

Cilia

are small hairs located in the bronchi. The mucus in the respiratory tract is expelled by the cilia.



Bronchioles

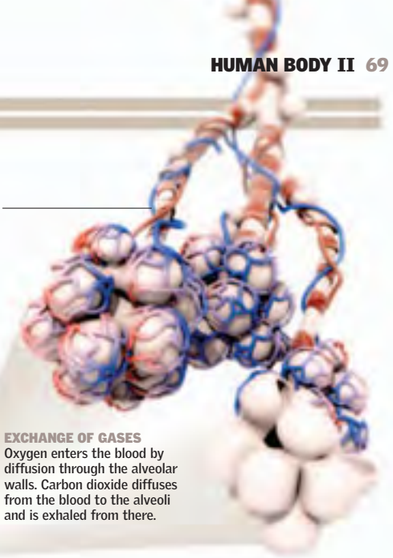
Terminations located in the bronchi of each lung. Their function is key in the respiratory system: they connect with the alveoli, where the gaseous exchange takes place. If the bronchioles are damaged, natural breathing is impeded.

BRONCHI

These branched structures end in bronchioles, which are connected to the alveoli through air ducts.

Alveoli

These microscopic bags of air in the lungs have a structure with thin, elastic walls. They take in air from the ducts of bronchioles. The inner surface of the alveoli has macrophages that destroy bacteria. If a significant number of alveoli are destroyed, breathing can become difficult.



EXCHANGE OF GASES

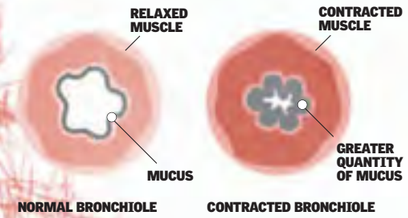
Oxygen enters the blood by diffusion through the alveolar walls. Carbon dioxide diffuses from the blood to the alveoli and is exhaled from there.

Asthma

Asthma attacks are characterized by recurrent episodes of an out-of-breath feeling caused by the constriction of the airways. The smallest bronchi and bronchioles become inflamed and filled with mucus, causing difficulty in breathing. The most recurrent type of asthma is the allergic kind, which develops in childhood.

BRONCHIOLE CONTRACTION

Normally the bronchiole is relaxed, and the air flows freely. Upon contraction of the muscle, there is a shortage of air and the space for its circulation is limited.



Lung Cancer

The growth of cancer cells (pictured) is caused by tobacco in 90 percent of cases. Of the 4,000 chemical substances in tobacco, 40 components have a carcinogenic potential that causes the appearance of atypical cells. When these cells grow, cancer cells multiply.

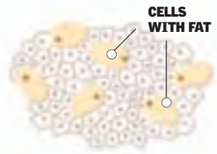
NUCLEUS
is elongated and projects extensions outside the cell wall. It contains chromatin, DNA, and proteins.

Excesses in the Digestive System

Diseases that affect the organs of the digestive system, such as the stomach, pancreas, and liver, find their origin in alcoholic drinks, poor nutrition, or bacteria that break down the layers of tissue and harm the organs. Diseases, such as cirrhosis, hepatitis B, gallstones, and ulcers, can lead to irreparable damage in different parts of the body.

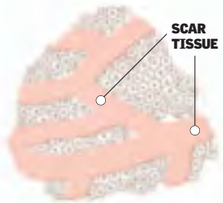
Cirrhosis

This liver disease causes fibrosis and dysfunction of the liver. The main causes are chronic alcoholism and infection with the hepatitis C virus. Cirrhosis can cause a buildup of fluid in the abdomen (ascites), clotting disorders, increased blood pressure in the hepatic veins of the digestive tract, with dilation and risk of rupture, and confusion or changes in the level of consciousness (hepatic encephalopathy). Some symptoms are edema in the lower limbs, bloody vomit, jaundice (yellowish skin), generalized weakness, weight loss, and kidney disorders.

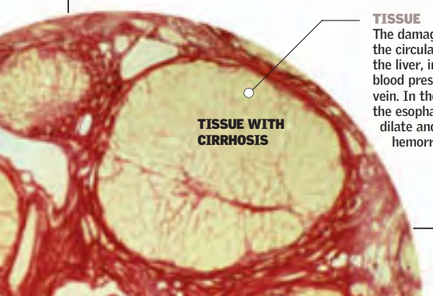


A FATTY LIVER
can appear as a result of excessive alcohol consumption. The liver contains fat cells that infiltrate, become larger, and enlarge the liver.

B ALCOHOLIC HEPATITIS
Alcohol consumption induces enzymes to produce acetaldehyde, which generates inflammation. This damages the hepatic cells, impairing normal liver function.



C CIRRHOSIS
Bands of damaged tissue separate the cells. This stage of destruction is irreversible and can also stem from other causes, such as viral hepatitis.



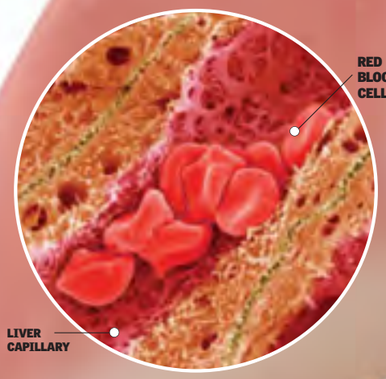
TISSUE
The damaged tissue affects the circulation of blood in the liver, increasing the blood pressure in the portal vein. In the lower part of the esophagus, the veins dilate and a digestive hemorrhage can occur.

Liver

The blood coming from the organs of the digestive system reaches the liver through the portal vein. The liver removes the toxic by-products from the body, synthesizes and stores nutrients, and contributes to the digestion of food by producing bile.

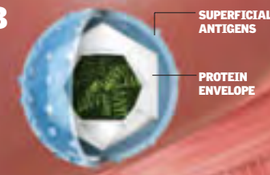
Cleaning

Substances carried in the blood are modified during their passage through the liver, which cleans and purifies the blood supply, breaks down certain chemical substances, and synthesizes others.



Hepatitis B

is transmitted by blood and blood products, contaminated needles, unprotected sex, and from mother to child during birth.



Stomach

Food substances are stored here for some time before proceeding to the intestine. By this point, the food is in an advanced state of digestion, in which the original substances have been converted into simpler ones that pass through the intestinal wall and into the blood.

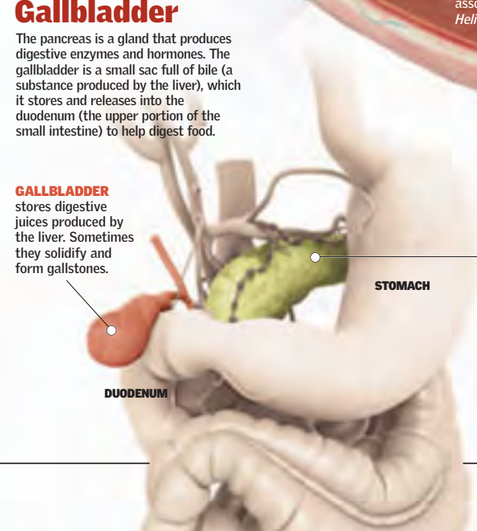
INJURED AREA

Gastritis

An inflammation of the mucous membrane of the stomach, it may have various causes, including alcohol consumption, anti-inflammatory medication, and smoking tobacco. It is also associated with *Helicobacter pylori* bacteria.

Pancreas and Gallbladder

The pancreas is a gland that produces digestive enzymes and hormones. The gallbladder is a small sac full of bile (a substance produced by the liver), which it stores and releases into the duodenum (the upper portion of the small intestine) to help digest food.

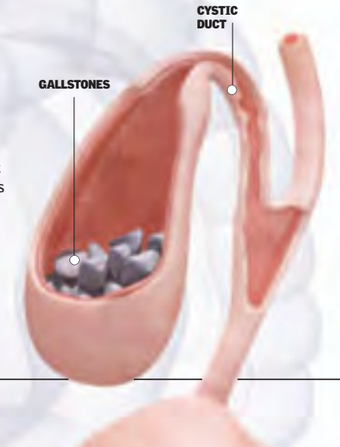


GALLBLADDER
stores digestive juices produced by the liver. Sometimes they solidify and form gallstones.

PANCREAS
secretes pancreatic juices, which contain the enzymes necessary to digest foods, into the duodenum.

Gallstones

form inside the gallbladder, an organ that stores the bile secreted by the liver. Bile is a solution of water, salts, lecithin, cholesterol, and other substances. If the concentration of these components changes, stones may form. They can be as small as a grain of sand or can grow to about 1 inch (3 cm) in diameter depending on how long they have been forming.



1 OBSTRUCTION
The bile is blocked from leaving the gallbladder by a gallstone. This causes pain and inflammation of the gallbladder.

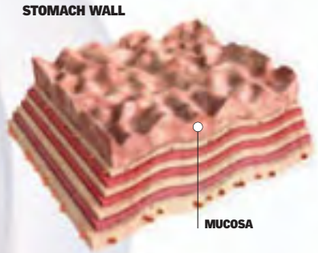
2 INFLAMMATION
The inflammation progresses by means of various mechanisms. The contents of the gallbladder can become infected and form pus.

3 RUPTURE
If the process continues and the inflammation is very significant, the gallbladder could rupture.

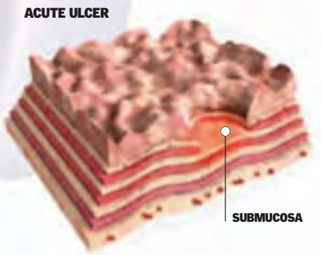
4 CONTRACTION
If the process is repeated, the gallbladder could shrink and lose its shape.

Peptic Ulcer

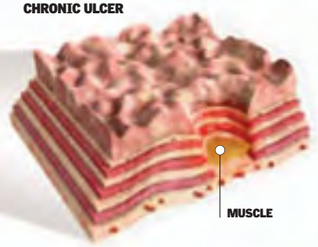
A sore in the mucous membrane of the stomach or duodenum. Peptic ulcers are common, and one of the main causes is infection by the bacterium *Helicobacter pylori*. However, some are caused by the prolonged use of nonsteroidal anti-inflammatory agents, such as aspirin and ibuprofen. In some instances, stomach or pancreatic tumors can cause ulcers. The relationship between ulcers and certain types of foods or stress has not been clearly demonstrated. The main symptom is abdominal pain that is more common at night, when the stomach is empty, or two to three hours after eating.



1 EARLY STAGES
When the barrier of protective mucosa is altered and the stomach juices come into contact with the cells of the mucosa, erosion occurs.



2 DEEPENING
The sore completely penetrates the mucosa, reaching the muscle layer of the mucosa and submucosa. An ulcer is formed.



3 COMPLICATIONS
As the stomach wall is more deeply eroded, a large artery could be damaged enough to cause a hemorrhage. It could also lead to peritonitis.

Intestines and Colon

Intestinal infections and inflammations are among the most common disorders of the digestive system. In developing nations, an increase in infant mortality has been due to some of these diseases. Many are bacterial and can be treated with the ingestion of fluids or antibiotics, but others can be caused by a problem of the digestive system.

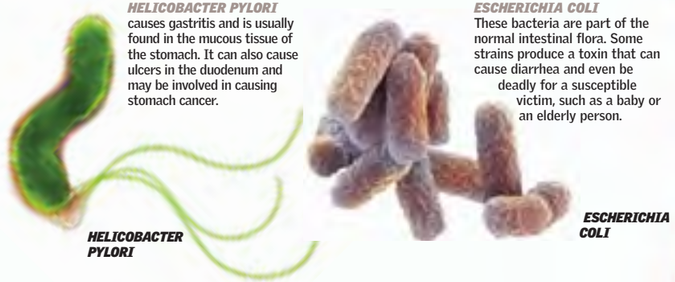
Intestinal Infections

The most common intestinal infection is viral gastroenteritis, but it can also be caused by bacteria or protozoa. Almost all infections are transmitted by ingesting contaminated water or food. The most common symptoms are vomiting, diarrhea, and abdominal pain. Viral gastroenteritis is a self-limiting process that resolves itself in several days simply by replacing fluids to prevent dehydration, but other infections must be treated with antibiotics.

***GIARDIA* PARASITES**

HELICOBACTER PYLORI
causes gastritis and is usually found in the mucous tissue of the stomach. It can also cause ulcers in the duodenum and may be involved in causing stomach cancer.

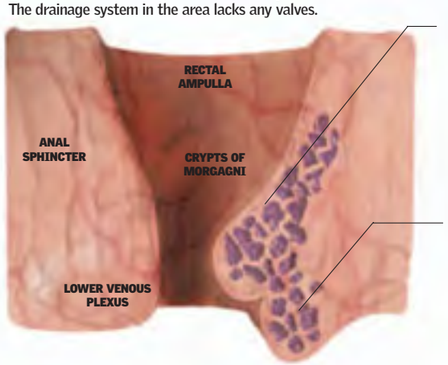
ESCHERICHIA COLI
These bacteria are part of the normal intestinal flora. Some strains produce a toxin that can cause diarrhea and even be deadly for a susceptible victim, such as a baby or an elderly person.



HELICOBACTER PYLORI ***ESCHERICHIA COLI***

Hemorrhoids

These dilatations of veins occur in the venous plexus in the mucosa of the rectum and anus. If the affected veins are in the superior plexus, they are called internal hemorrhoids. Those of the inferior venous plexus are located below the anorectal line and are covered by the outer skin. The drainage system in the area lacks any valves.

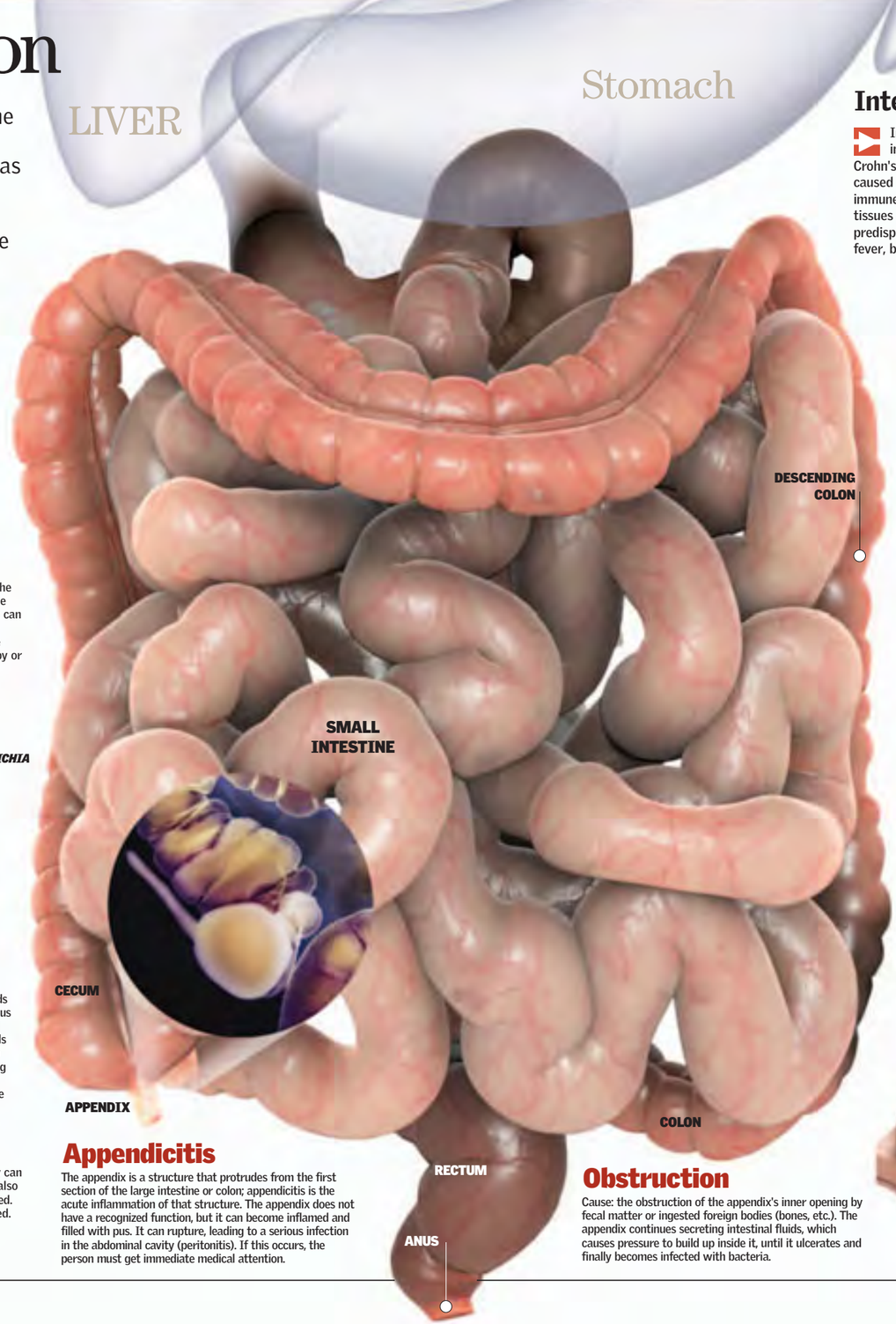


TYPES OF HEMORRHOIDS

There are two types of hemorrhoids: internal and external.

1 **INTERNAL**
Classified according to grades. Grade I hemorrhoids are located in the submucous tissue and bleed bright red blood. Grade II hemorrhoids protrude during defecation but recede once the pushing stops. Grade III come out while defecating, and Grade IV are irreducible and are always prolapsed.

2 **EXTERNAL**
Come from the inferior hemorrhoidal plexus. They can swell and cause pain and also become ulcerated and bleed. Thrombosis can be resolved.



Appendicitis

The appendix is a structure that protrudes from the first section of the large intestine or colon; appendicitis is the acute inflammation of that structure. The appendix does not have a recognized function, but it can become inflamed and filled with pus. It can rupture, leading to a serious infection in the abdominal cavity (peritonitis). If this occurs, the person must get immediate medical attention.

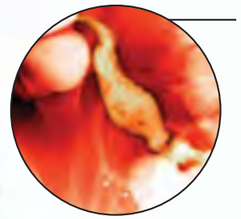
Obstruction

Cause: the obstruction of the appendix's inner opening by fecal matter or ingested foreign bodies (bones, etc.). The appendix continues secreting intestinal fluids, which causes pressure to build up inside it, until it ulcerates and finally becomes infected with bacteria.

GASTRIC VILLI
This image shows the walls of the duodenum where the gastric villi can be seen.

Intestinal Inflammation

Intestinal inflammations include ulcerative colitis and Crohn's disease. They can be caused by an attack of the immune system on the body's own tissues or by genetic predisposition. Symptoms include fever, blood loss, abdominal pain, and diarrhea. These conditions can be diagnosed with X-rays, a colonoscopy, or a biopsy of the intestinal tissue. The treatment might include anti-inflammatory drugs.



Colitis

Ulcerative colitis is an inflammatory disease of the colon and rectum. It is characterized by the inflammation and ulceration of the colon's inner wall. Typical symptoms include diarrhea (sometimes bloody) and frequent abdominal pain.

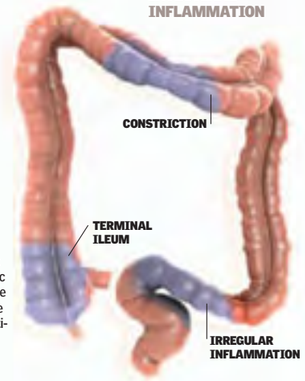
Crohn's Disease

Crohn's disease is a chronic autoimmune condition in which the individual's immune system attacks its own intestine, causing inflammation.

Ulcer

A peptic ulcer is a sore, or chronic erosive lesion, of the lining of the stomach or the duodenum (the first section of the small intestine). Peptic ulcers are common and can originate from a bacterial infection or in some cases from the prolonged use of anti-inflammatory drugs.

INTESTINAL INFLAMMATION



Colon Cancer

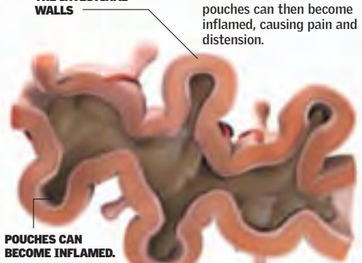
This type of cancer is one of the most common in industrialized nations. Risk factors include family medical history, intestinal polyps, and advanced age. The symptoms are blood in the stool, a change in intestinal habits, and abdominal pain. People over 50 years of age should be evaluated by their doctor to check for the presence of blood in the stool (as seen in the photo), and if this test is positive a colonoscopy should be performed.

Diverticulitis

The inflammation or infection of a pouch, called a diverticulum, formed in the wall of the large intestine (colon). It is believed to be caused by the slow movement of food through the intestines, which builds up a constant pressure. This increases and pushes on the inside walls of the colon, forming pouches. Ingested food or stool becomes trapped in a pouch, leading to inflammation and infection.

1 **HARD, DRY STOOL**
Bulky, soft stool passes easily through the colon. But if the stool is hard and dry, the force of the contractions increases, putting more pressure on the walls of the colon.

2 **DIVERTICULA**
Increasing pressure against the inner intestinal lining forms pouches in weak spots of the muscle wall. These pouches can then become inflamed, causing pain and distension.



Allergies: A Modern Evil

Sneezing and watery eyes, rashes and skin irritation, swelling, and itching. These are just some of the most common symptoms of allergies, a condition that affects millions of people throughout the world, especially in developed countries. What is the cause of allergies? The immune system does not function properly: it overreacts, attacking foreign substances that normally would not cause any harm. These invaders, called allergens, might include pollen, mold, and dust mites, among many other possibilities.

An Attack on an Innocent

In developed countries, the percentage of the population affected by allergies has increased. One reason for this epidemic of modernity is the obsession with cleanliness. This means that the body, from infancy, is not exposed to enough dirt to train the immune system, which then reacts inappropriately to any foreign substance, no matter how harmless. Upon the first exposure to an allergen, the immune system becomes sensitized. In subsequent exposures, an allergic reaction occurs, which can range from a skin rash to various breathing problems. The reaction varies from person to person.

3 BURST
When allergens are present, the cells that help the body fight infections malfunction and respond with unnecessary chemical defenses.

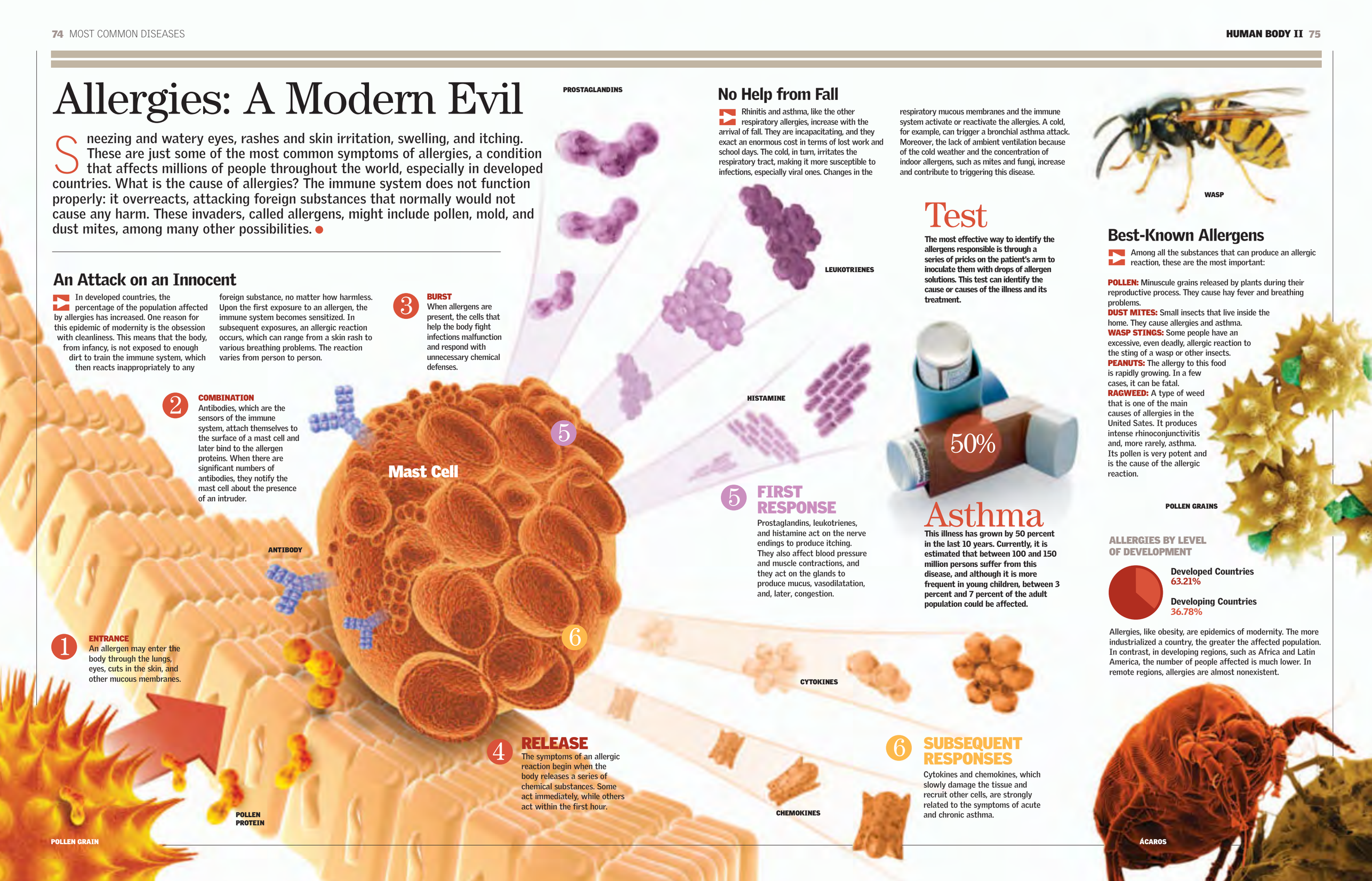
2 COMBINATION
Antibodies, which are the sensors of the immune system, attach themselves to the surface of a mast cell and later bind to the allergen proteins. When there are significant numbers of antibodies, they notify the mast cell about the presence of an intruder.

1 ENTRANCE
An allergen may enter the body through the lungs, eyes, cuts in the skin, and other mucous membranes.

4 RELEASE
The symptoms of an allergic reaction begin when the body releases a series of chemical substances. Some act immediately, while others act within the first hour.

5 FIRST RESPONSE
Prostaglandins, leukotrienes, and histamine act on the nerve endings to produce itching. They also affect blood pressure and muscle contractions, and they act on the glands to produce mucus, vasodilatation, and, later, congestion.

6 SUBSEQUENT RESPONSES
Cytokines and chemokines, which slowly damage the tissue and recruit other cells, are strongly related to the symptoms of acute and chronic asthma.



No Help from Fall

Rhinitis and asthma, like the other respiratory allergies, increase with the arrival of fall. They are incapacitating, and they exact an enormous cost in terms of lost work and school days. The cold, in turn, irritates the respiratory tract, making it more susceptible to infections, especially viral ones. Changes in the respiratory mucous membranes and the immune system activate or reactivate the allergies. A cold, for example, can trigger a bronchial asthma attack. Moreover, the lack of ambient ventilation because of the cold weather and the concentration of indoor allergens, such as mites and fungi, increase and contribute to triggering this disease.

Test

The most effective way to identify the allergens responsible is through a series of pricks on the patient's arm to inoculate them with drops of allergen solutions. This test can identify the cause or causes of the illness and its treatment.

Asthma

This illness has grown by 50 percent in the last 10 years. Currently, it is estimated that between 100 and 150 million persons suffer from this disease, and although it is more frequent in young children, between 3 percent and 7 percent of the adult population could be affected.

Best-Known Allergens

Among all the substances that can produce an allergic reaction, these are the most important:

POLLEN: Minuscule grains released by plants during their reproductive process. They cause hay fever and breathing problems.
DUST MITES: Small insects that live inside the home. They cause allergies and asthma.
WASP STINGS: Some people have an excessive, even deadly, allergic reaction to the sting of a wasp or other insects.
PEANUTS: The allergy to this food is rapidly growing. In a few cases, it can be fatal.
RAGWEED: A type of weed that is one of the main causes of allergies in the United Sates. It produces intense rhinoconjunctivitis and, more rarely, asthma. Its pollen is very potent and is the cause of the allergic reaction.

ALLERGIES BY LEVEL OF DEVELOPMENT

Developed Countries
63.21%

Developing Countries
36.78%

Allergies, like obesity, are epidemics of modernity. The more industrialized a country, the greater the affected population. In contrast, in developing regions, such as Africa and Latin America, the number of people affected is much lower. In remote regions, allergies are almost nonexistent.

AIDS

CD4-positive T Lymphocyte
Immune system cell that defends the body against infections

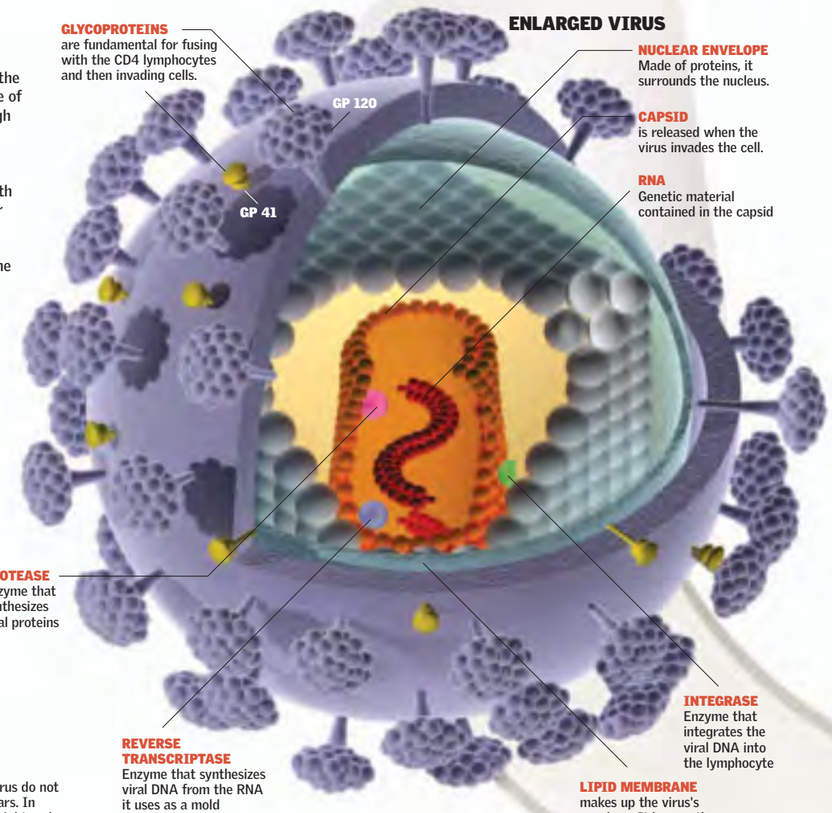
Acquired Immune Deficiency Syndrome (AIDS) is still considered one of the most important epidemics of the 21st century. Some 40 million people are infected with HIV (human immunodeficiency virus), the virus that causes AIDS; most of them are in Africa. Scientific research is aimed at finding a remedy to stop the development of the virus, but until now they have only produced therapies that slow viral activity.

The AIDS Virus

Human immunodeficiency virus (HIV) is the cause of AIDS. This virus destroys a type of white blood cell, the CD4 T lymphocyte, through the interaction of the viral DNA with the lymphocyte's DNA. These lymphocytes are essential to the immune system's fight against infections. For this reason, persons infected with HIV can suffer severe diseases, and even minor conditions, such as a cold, might be difficult to cure. However, not all those infected with HIV suffer from AIDS, which is the final stage of the disease. A person with HIV is seropositive. When the level of CD4-positive T lymphocytes goes below 200 cells per 1 mm³ of blood, the disease progresses to the stage of AIDS.

History and Evolution

The "age of AIDS" began on June 5, 1981. The U.S. Centers for Disease Control found patients with pneumonia that simultaneously suffered from Kaposi sarcoma, a malignant tumor of the skin. It was noted that all the patients had a notable depletion of CD4-positive T lymphocytes. Unprotected sex and the use of needles with infected blood were the typical causes at that time. Today mother-to-child transmission and transfusions of blood and blood products play an important role.



Symptoms of the Disease

Many people infected with the virus do not develop symptoms for several years. In earlier stages, they might lose weight and have fever without any clear cause and in later stages have frequent diarrhea. Those severely infected are predisposed to develop various infections and cancers.

Brain If damaged, it can cause vision problems, weakness, and paralysis.
Lungs The most common disease that can be contracted is pneumonia.
Skin The appearance of Kaposi's sarcoma, brown and blue spots on the skin, is generally associated with AIDS.
Digestive system Persistent diarrhea due to an infection of the gastrointestinal tract by parasites such as *Giardia lamblia* can result.

How the AIDS Virus Works

The virus uses its layer of proteins to attach to the cell that will harbor it. A specific protein (gp120) fuses with a receptor on the CD4-positive T lymphocyte. After the immune system loses many cells, the body is left susceptible to many diseases. Ten years might pass from the time of infection until the development of full-blown AIDS.

1 VIRAL STRUCTURE
Before attachment, the virus's envelope contains a capsid that carries the genetic material. With this material, which contains RNA, the virus will begin to act on the lymphocyte's DNA. The envelope that covers the capsid is made of protein.

2 ATTACHMENT
Through certain receptors on the cell surface, the virus's proteins can link with proteins on the CD4-positive T lymphocyte. The glycoprotein gp120 that covers the virus enables it to fuse with the lymphocyte.

3 INVASION
The virus penetrates the cell and infects it. The capsid is released, and with it goes all the genetic material (RNA) necessary to begin the process of transcription of RNA into viral DNA.

4 TRANSCRIPTION
The RNA serves as a mold to synthesize viral DNA. Reverse transcriptase produces the DNA, preparing it to be inserted into the structure of the CD4 T lymphocyte.

5 INTEGRATION
Integrase inserts the viral DNA into the DNA strand of the lymphocyte. The normal activity of the white blood cell changes because of the new DNA.

6 SYNTHESIS
Viral protein chains begin to be synthesized. The protease cuts these chains and converts them into individual proteins.

7 OUTWARD PUSH
The new virus model begins to come out of the infected cell. It takes part of the cell membrane with it.

8 MIGRATION
The virus completely detaches from the infected cell and is free once again. It contains a structure identical to the original.

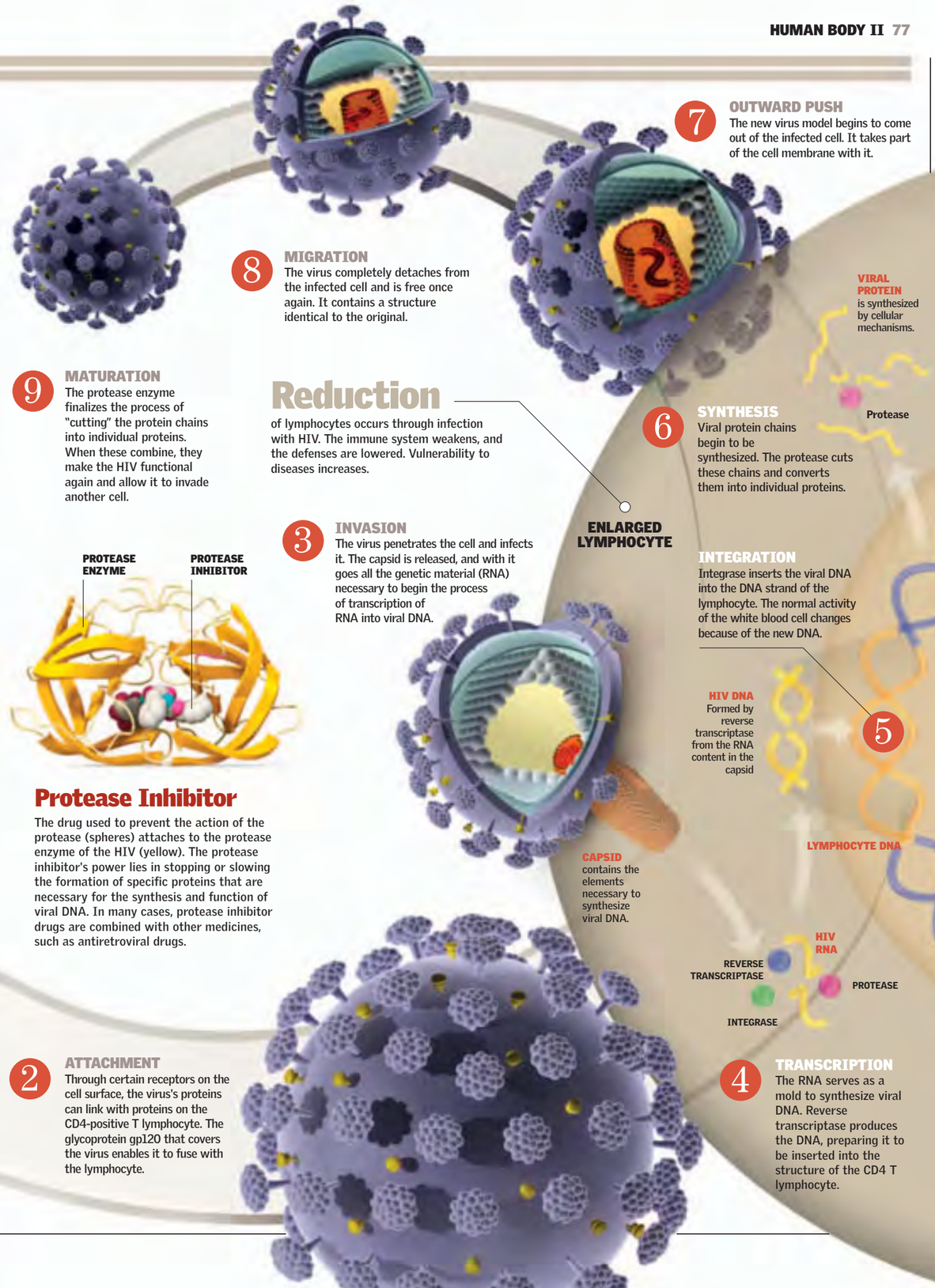
9 MATURATION
The protease enzyme finalizes the process of "cutting" the protein chains into individual proteins. When these combine, they make the HIV functional again and allow it to invade another cell.

Reduction

of lymphocytes occurs through infection with HIV. The immune system weakens, and the defenses are lowered. Vulnerability to diseases increases.

Protease Inhibitor

The drug used to prevent the action of the protease (spheres) attaches to the protease enzyme of the HIV (yellow). The protease inhibitor's power lies in stopping or slowing the formation of specific proteins that are necessary for the synthesis and function of viral DNA. In many cases, protease inhibitor drugs are combined with other medicines, such as antiretroviral drugs.



Advanced Technology

VIRTUAL REALITY
This image shows a microscopic submarine, small enough to travel through an artery.

EARLY DIAGNOSIS 80-81
LASER SURGERY 82-83
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EN ROUTE TO ETERNITY 90-91

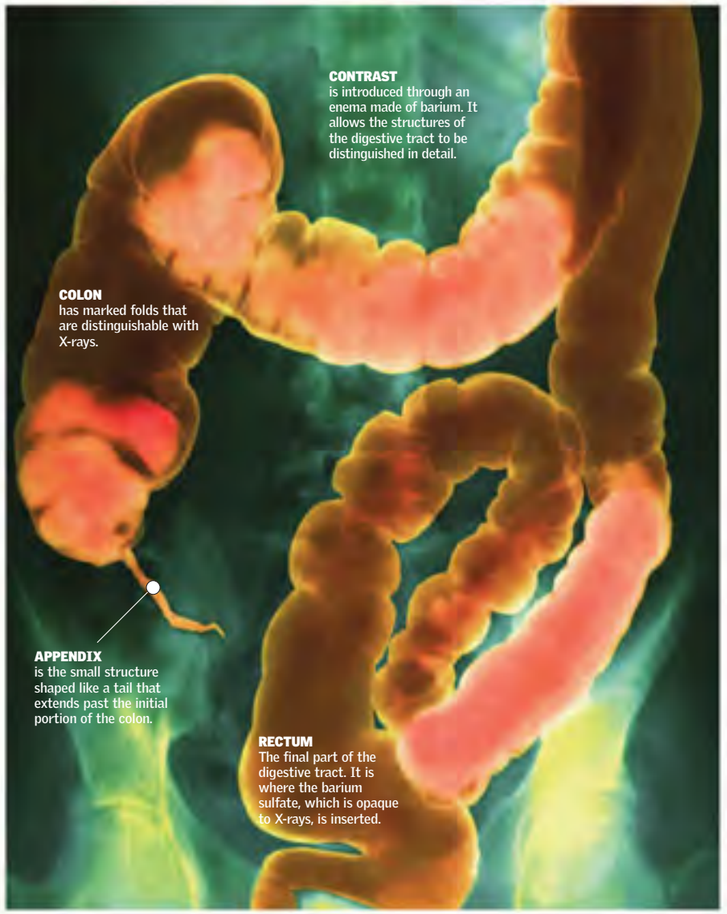
Technology, in the service of medicine, has permitted the understanding and prevention of many serious diseases thanks to the study of early diagnostic techniques, such as magnetic resonance imaging and positron emission tomography, which provide images of the interior of the body. Future decades, however, promise to bring even more exciting developments. In this chapter, we will tell you about exciting developments like nanomedicine, whose main objective is to cure diseases from inside the body. For this purpose, devices smaller in diameter than a human hair have been developed. Among other dreams in the minds of scientists is that of preventing the degeneration of nerve cells. Enjoy the fascinating information offered in this chapter! ●

Early Diagnosis

There are various methods of examining the body to search for possible diseases. One of the most novel procedures is positron emission tomography (PET), which is able to detect the formation of a malignant tumor before it becomes visible through other methods. It is also useful for evaluating a person's response to a specific treatment and for measuring heart and brain function.

X-Rays

The simple emission of X-rays consists of sending out short electromagnetic waves. After passing through the body, they reach a photographic film and create shadow images. The denser structures, like bone, absorb more X-rays and appear white, whereas the softer tissues appear gray. In other cases, a fluid must be used to fill hollow structures and generate useful images. To examine the digestive tract, for example, a barium sulfate mixture must be ingested.

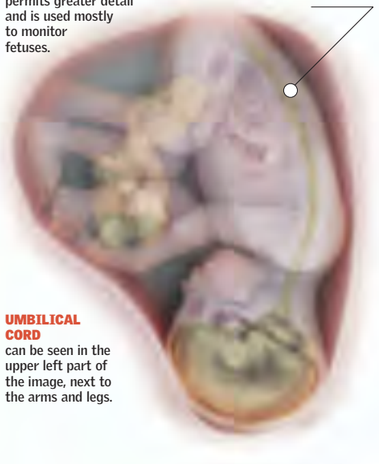


Scanning Methods

The different techniques for exploring the body aim to detect possible anomalies in the organs and tissues. The latest developments, such as magnetic resonance imaging and positron emission tomography, have surpassed classic X-ray methods. It is now possible to obtain detailed images of tissues and of the metabolic activity of tumor cells.

3-D MAGNETIC RESONANCE IMAGING
permits greater detail and is used mostly to monitor fetuses.

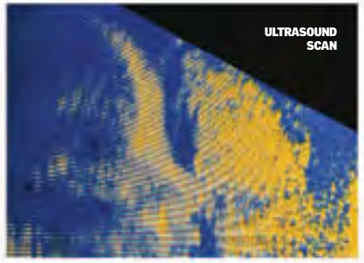
SPINAL CORD
Visible and colored green, like the brain



UMBILICAL CORD
can be seen in the upper left part of the image, next to the arms and legs.

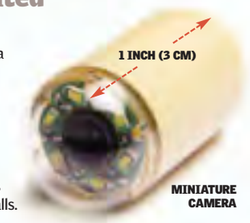
Ultrasound

A device called a transducer emits extremely high frequency sound waves. The transducer is passed back and forth over the part of the body being examined. The sound waves return to the transducer as an echo and are analyzed by a computer.



Encapsulated Camera

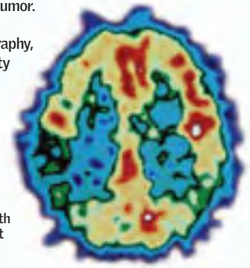
A miniature camera enters the body through a capsule and takes detailed pictures of the digestive tract. It travels using the natural movements of the intestinal walls.



Positron Emission Tomography

This technology enables doctors to obtain detailed information about metabolic issues, such as the cell activity of a tumor. When combined with computerized tomography, it provides high-quality images and advanced knowledge regarding diseases such as cancer. This way, it may be possible to detect an illness before it spreads.

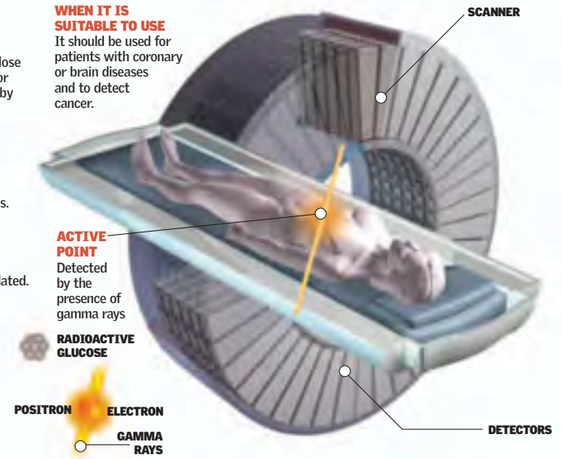
METABOLIC ACTIVITY
This scan shows the activity in a brain with Alzheimer's disease. There are few zones with high activity (red); most are low (blue-green).



HOW IT WORKS

1. **INJECTION** The patient receives a dose of radioactive glucose, or FDG, which is taken up by affected organs.
2. **POSITRONS** The active tumors take up large amounts of glucose. When the FDG decays, it emits positrons.
3. **GAMMA RAYS** are emitted when the positrons collide with electrons and are annihilated.
4. **IMAGES** A computer receives the rays and converts them into images that provide details about possible tumors.

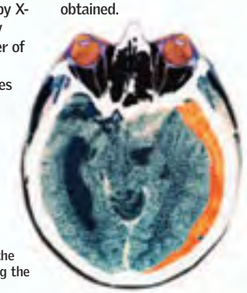
WHEN IT IS SUITABLE TO USE
It should be used for patients with coronary or brain diseases and to detect cancer.



Computerized Tomography

Computerized tomography (CT) provides information about regions denser than those typically penetrated by X-rays. The tomography covers each millimeter of the body's contour, providing many images of cross sections of the body. By combining these images, a three-dimensional grayscale picture of a particular organ can be obtained.

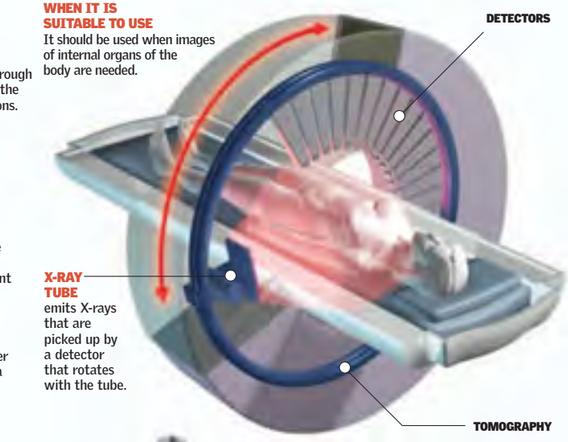
INTERNAL HEMORRHAGE
In this CT scan, a hematoma (in orange) can be seen that was formed from a blood clot after an injury to the membranes surrounding the brain.



HOW IT WORKS

1. **SCAN** The patient enters the tomography machine through an opening that divides the body contour into sections.
2. **X-RAY TUBE** rotates simultaneously with the detector to completely X-ray the patient.
3. **RECEPTION** The detectors sense the intensity of the rays as they pass over each point of the body.
4. **IMAGE** The information is processed by a computer that integrates the data into images.

WHEN IT IS SUITABLE TO USE
It should be used when images of internal organs of the body are needed.



Magnetic Resonance Imaging

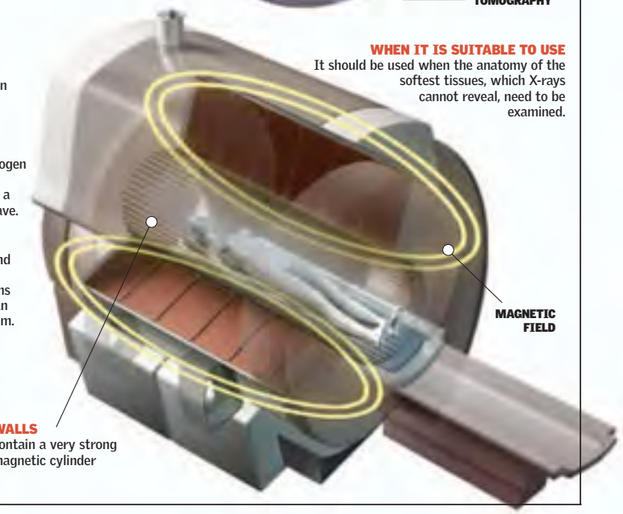
A technique that uses a cylindrical chamber capable of producing a magnetic field 40,000 times stronger than the Earth's. Unlike X-rays, magnetic resonance allows imaging of soft tissues (like fat) and from every angle. It provides the most detailed images and is used most frequently for examining the brain.

BRAIN
The fibers of the nerve cells that transmit electrical signals are shown in color.

HOW IT WORKS

1. **MAGNETIC FIELD** acts on the hydrogen atoms of the body when the patient enters the magnetized chamber.
2. **RADIO WAVES** are applied to the hydrogen atoms. Upon receiving these waves, they emit a corresponding radio wave.
3. **PROCESSING** A computer receives and processes the signals emitted by the atoms and then builds an image from them.

WHEN IT IS SUITABLE TO USE
It should be used when the anatomy of the softest tissues, which X-rays cannot reveal, need to be examined.



Laser Surgery

Surgeries performed with laser beam techniques are much simpler than traditional procedures. Lasers are frequently used in eye surgery. They can close blood vessels in the retina. Lasers can also burn papillomas (benign epithelial tumors) and excise precancerous lesions from the mouth without scarring. Currently lasers are used to break down kidney stones and to open clogged arteries. ●

Laser Angioplasty

When fatty deposits (atheromas) accumulate in the arteries, plaque forms, and the internal channel for blood flow narrows. Laser angioplasty can be used to eliminate this plaque. In this operation, a catheter with a small balloon is used. The balloon is introduced into the artery and is inflated to momentarily cut off the circulation. The plaque is removed easily by a laser emitter located at the tip of the catheter. The laser angioplasty operation is quick, and the patient's recovery period is usually short. Laser angioplasty is recommended when only one artery is blocked.

1 INCISION
An incision is made in an arm or leg or in an artery. The catheter is introduced. Guided by X-rays or ultrasound, it is directed toward the location of the blocked artery.

BEFORE THE OPERATION
an incision is made in the patient's arm or leg.

2 LOCATION
The catheter is directed toward the location of the blockage. The balloon is inflated, and it presses against the arterial walls. Blood circulation is temporarily cut off to permit the removal of plaque.

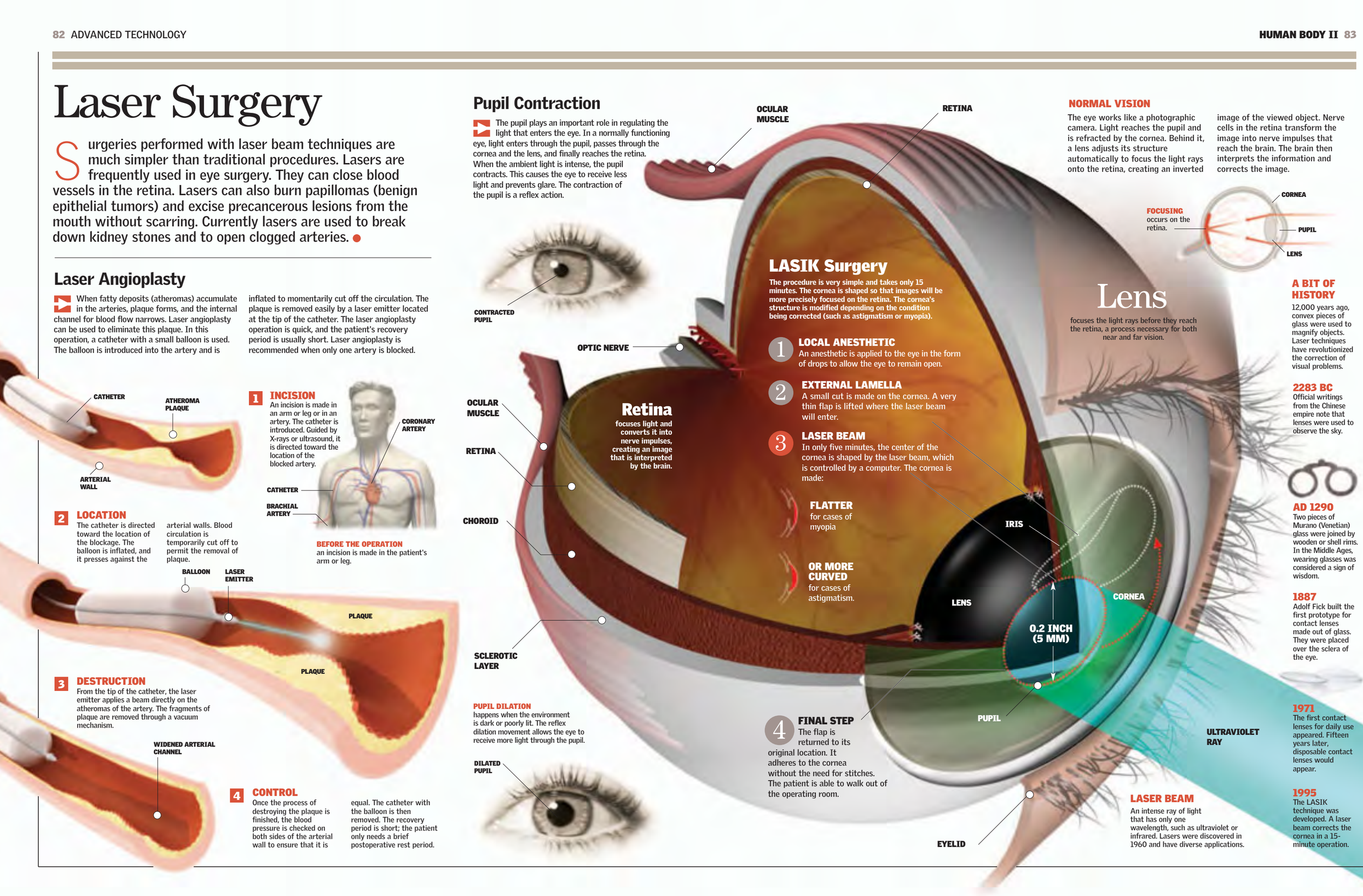
3 DESTRUCTION
From the tip of the catheter, the laser emitter applies a beam directly on the atheromas of the artery. The fragments of plaque are removed through a vacuum mechanism.

4 CONTROL
Once the process of destroying the plaque is finished, the blood pressure is checked on both sides of the arterial wall to ensure that it is equal. The catheter with the balloon is then removed. The recovery period is short; the patient only needs a brief postoperative rest period.

Pupil Contraction

The pupil plays an important role in regulating the light that enters the eye. In a normally functioning eye, light enters through the pupil, passes through the cornea and the lens, and finally reaches the retina. When the ambient light is intense, the pupil contracts. This causes the eye to receive less light and prevents glare. The contraction of the pupil is a reflex action.

PUPIL DILATION
happens when the environment is dark or poorly lit. The reflex dilation movement allows the eye to receive more light through the pupil.



Retina

focuses light and converts it into nerve impulses, creating an image that is interpreted by the brain.

LASIK Surgery

The procedure is very simple and takes only 15 minutes. The cornea is shaped so that images will be more precisely focused on the retina. The cornea's structure is modified depending on the condition being corrected (such as astigmatism or myopia).

1 LOCAL ANESTHETIC
An anesthetic is applied to the eye in the form of drops to allow the eye to remain open.

2 EXTERNAL LAMELLA
A small cut is made on the cornea. A very thin flap is lifted where the laser beam will enter.

3 LASER BEAM
In only five minutes, the center of the cornea is shaped by the laser beam, which is controlled by a computer. The cornea is made:

FLATTER
for cases of myopia

OR MORE CURVED
for cases of astigmatism.

4 FINAL STEP
The flap is returned to its original location. It adheres to the cornea without the need for stitches. The patient is able to walk out of the operating room.

ULTRAVIOLET RAY

LASER BEAM
An intense ray of light that has only one wavelength, such as ultraviolet or infrared. Lasers were discovered in 1960 and have diverse applications.

NORMAL VISION

The eye works like a photographic camera. Light reaches the pupil and is refracted by the cornea. Behind it, a lens adjusts its structure automatically to focus the light rays onto the retina, creating an inverted image of the viewed object. Nerve cells in the retina transform the image into nerve impulses that reach the brain. The brain then interprets the information and corrects the image.

FOCUSING
occurs on the retina.

Lens

focuses the light rays before they reach the retina, a process necessary for both near and far vision.

A BIT OF HISTORY

12,000 years ago, convex pieces of glass were used to magnify objects. Laser techniques have revolutionized the correction of visual problems.

2283 BC
Official writings from the Chinese empire note that lenses were used to observe the sky.

AD 1290
Two pieces of Murano (Venetian) glass were joined by wooden or shell rims. In the Middle Ages, wearing glasses was considered a sign of wisdom.

1887
Adolf Fick built the first prototype for contact lenses made out of glass. They were placed over the sclera of the eye.

1971
The first contact lenses for daily use appeared. Fifteen years later, disposable contact lenses would appear.

1995
The LASIK technique was developed. A laser beam corrects the cornea in a 15-minute operation.

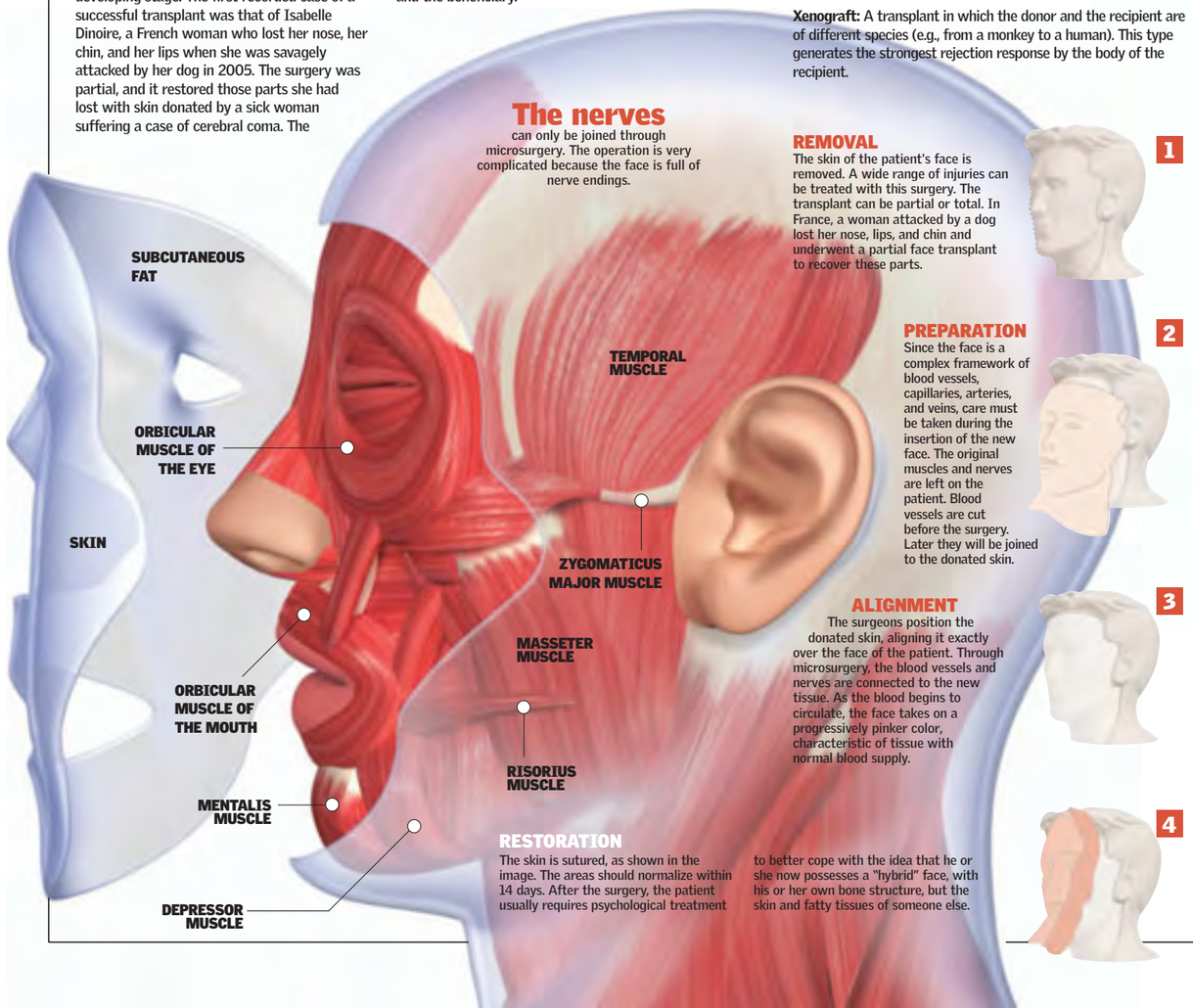
Transplants

When the possibilities for treating certain diseases run out, the only remaining alternative is to replace the sick organ with another one through a transplant. The organs can come from a live person (as long as it does not cause harm to that person, as in the case of kidney donation) or from a donor corpse. Today the most novel transplant is the face transplant, which involves working with many nerves and is highly complex.

The Mouth and Nose of Another Person

The operation for replacing the damaged face (generally due to burns) is still in its developing stage. The first recorded case of a successful transplant was that of Isabelle Dinoire, a French woman who lost her nose, her chin, and her lips when she was savagely attacked by her dog in 2005. The surgery was partial, and it restored those parts she had lost with skin donated by a sick woman suffering a case of cerebral coma. The complex operation included the ligation of blood vessels and nerves between the donating tissue and the beneficiary.

The nerves can only be joined through microsurgery. The operation is very complicated because the face is full of nerve endings.



Organ Transplants

Of the two types of transplant operations (organs and tissues), organ transplants are by far the more difficult. They require complex surgeries to achieve the splicing of vessels and ducts. Tissue transplants are simpler: cells are injected, to be implanted later.

TYPES OF TRANSPLANTS

Allograft: Consists of the donation of organs from one individual to another genetically different individual of the same species.

Autograft: A transplant in which the donor and the recipient are the same person. The typical case is a skin graft from a healthy site to an injured one.

Isograft: A transplant in which the donor and the recipient are genetically identical.

Xenograft: A transplant in which the donor and the recipient are of different species (e.g., from a monkey to a human). This type generates the strongest rejection response by the body of the recipient.

1 REMOVAL
The skin of the patient's face is removed. A wide range of injuries can be treated with this surgery. The transplant can be partial or total. In France, a woman attacked by a dog lost her nose, lips, and chin and underwent a partial face transplant to recover these parts.

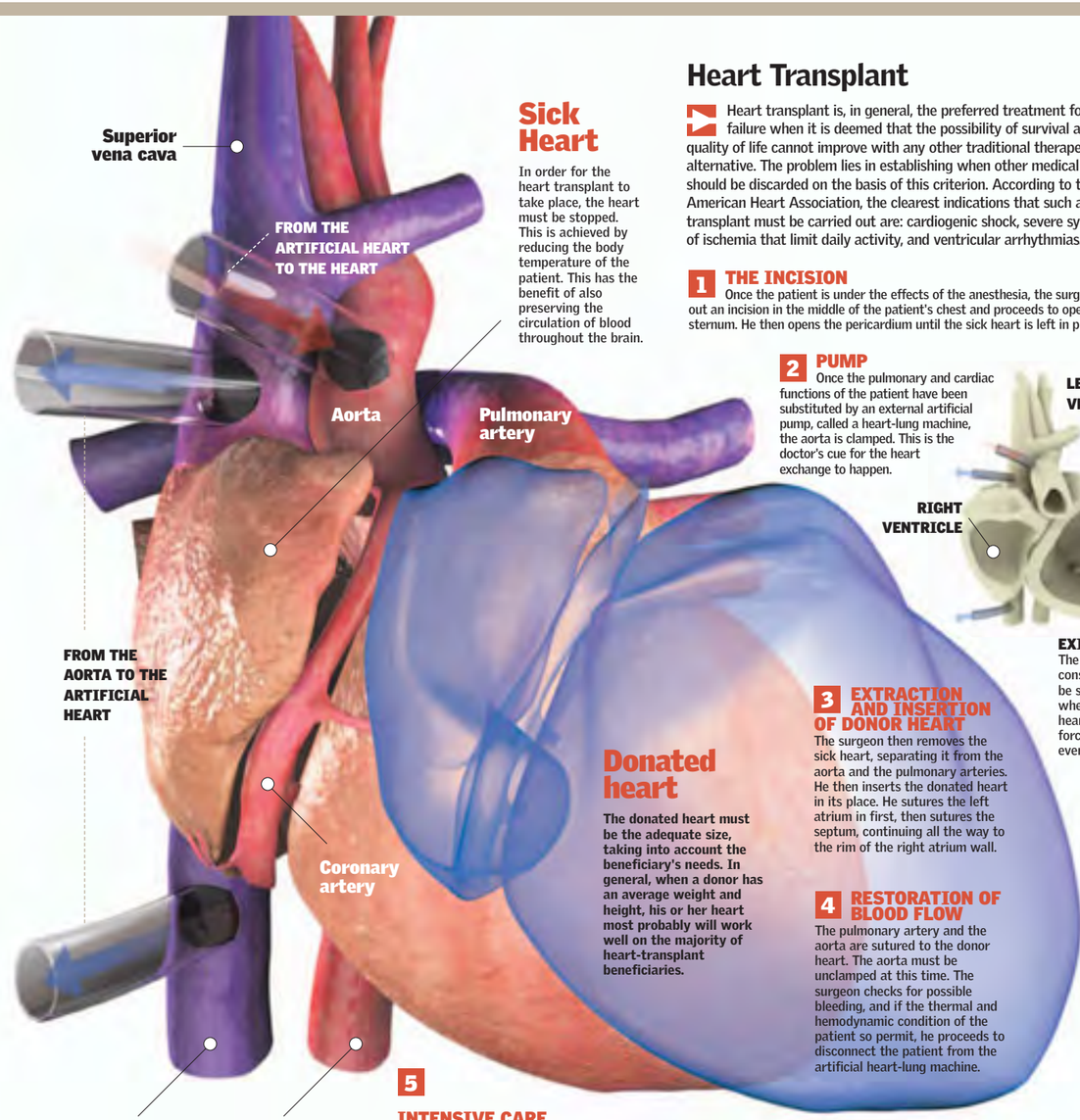
2 PREPARATION
Since the face is a complex framework of blood vessels, capillaries, arteries, and veins, care must be taken during the insertion of the new face. The original muscles and nerves are left on the patient. Blood vessels are cut before the surgery. Later they will be joined to the donated skin.

3 ALIGNMENT
The surgeons position the donated skin, aligning it exactly over the face of the patient. Through microsurgery, the blood vessels and nerves are connected to the new tissue. As the blood begins to circulate, the face takes on a progressively pinker color, characteristic of tissue with normal blood supply.

4 RESTORATION
The skin is sutured, as shown in the image. The areas should normalize within 14 days. After the surgery, the patient usually requires psychological treatment to better cope with the idea that he or she now possesses a "hybrid" face, with his or her own bone structure, but the skin and fatty tissues of someone else.

Heart Transplant

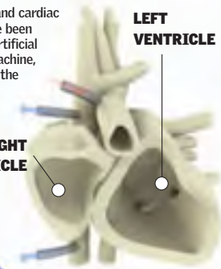
Heart transplant is, in general, the preferred treatment for heart failure when it is deemed that the possibility of survival and the quality of life cannot improve with any other traditional therapeutic alternative. The problem lies in establishing when other medical options should be discarded on the basis of this criterion. According to the American Heart Association, the clearest indications that such a transplant must be carried out are: cardiogenic shock, severe symptoms of ischemia that limit daily activity, and ventricular arrhythmias.



Sick Heart
In order for the heart transplant to take place, the heart must be stopped. This is achieved by reducing the body temperature of the patient. This has the benefit of also preserving the circulation of blood throughout the brain.

1 THE INCISION
Once the patient is under the effects of the anesthesia, the surgeon carries out an incision in the middle of the patient's chest and proceeds to open up the sternum. He then opens the pericardium until the sick heart is left in plain view.

2 PUMP
Once the pulmonary and cardiac functions of the patient have been substituted by an external artificial pump, called a heart-lung machine, the aorta is clamped. This is the doctor's cue for the heart exchange to happen.



3 EXTRACTION AND INSERTION OF DONOR HEART
The surgeon then removes the sick heart, separating it from the aorta and the pulmonary arteries. He then inserts the donated heart in its place. He sutures the left atrium in first, then sutures the septum, continuing all the way to the rim of the right atrium wall.

EXIT
The graft is considered to be successful when the new heart contracts forcefully and evenly.

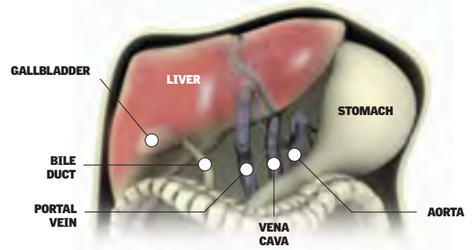
Donated heart
The donated heart must be the adequate size, taking into account the beneficiary's needs. In general, when a donor has an average weight and height, his or her heart most probably will work well on the majority of heart-transplant beneficiaries.

4 RESTORATION OF BLOOD FLOW
The pulmonary artery and the aorta are sutured to the donor heart. The aorta must be unclamped at this time. The surgeon checks for possible bleeding, and if the thermal and hemodynamic condition of the patient so permit, he proceeds to disconnect the patient from the artificial heart-lung machine.

5 INTENSIVE CARE
With the help of drainage tubes, the surgeon proceeds to close the breast incision. Finally, the patient, under constant surveillance, is transported to the intensive care unit. Once the postoperative period is over, the patient is released and begins a supervised ambulatory program in which he or she resumes physical movement such as walking.

Liver Transplant

People who suffer advanced, irreversible, life-threatening hepatic conditions now have the possibility of attempting a liver transplant. The most typical liver transplant cases are those of people who suffer chronic hepatitis or primary biliary cirrhosis, an autoimmune disease. Patients must not be infected in any way and cannot be suffering from any cardiac or pulmonary disease at the time.



1 DONATED LIVER
The organ, along with all its blood vessels and its bile duct, is removed immediately after the death of the donor.

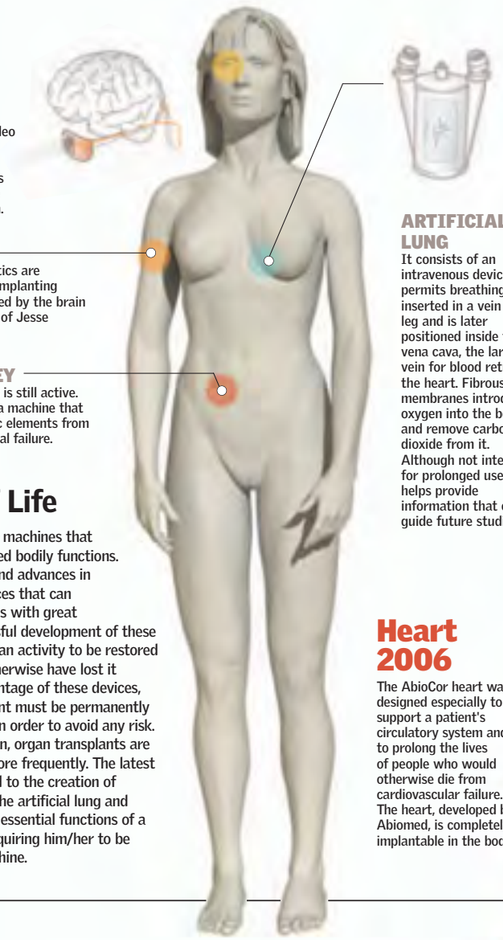
2 THE NEW LIVER
is fused with the vena cava and the rest of the blood vessels. The opposite ends of the bile duct are sutured. A probe is inserted inside the reconstructed bile duct to drain the blood and the bile.

Artificial Organs

The search for alternative solutions to save human lives has reached its maximum development thus far with the construction of artificial organs. The AbioCor artificial heart is currently being improved, and it is expected that by 2008 it will have a useful life of five years. Similarly bionics has made it possible for blind persons to perceive images through impulses transmitted to the brain by video footage from a camera that acts as a retina.

The Development of Bionics

Advancements in bionics have begun to fulfill the wish that has been searched for in recent years: artificial organs literally identical to the natural ones—that is, organs that will not come with a limited useful life like other electronic devices. The world has already witnessed 16 successful bionic eye implants, and bionic arms are currently under development. Jesse Sullivan, the first bionic man, is able to control his artificial arms with his brain: the nerves of the lost arms were embedded in his chest, and when the patient thinks about closing his fist, a portion of the muscles in his chest contract, and the electrodes that detect the muscle activity "tell" the bionic arm to close the fist.



A BIONIC EYE
A microchip is placed at the back of the human eye. It is connected to a miniature video camera, which captures images that the chip later processes. The information is then sent as impulses to the brain, which interprets them.

ARMS
Today surgeries for prosthetics are common. The possibility of implanting joints that could be controlled by the brain was achieved with the case of Jesse Sullivan in 2001.

ARTIFICIAL KIDNEY
Research to improve dialysis is still active. The patient is connected to a machine that removes impurities and toxic elements from the blood in the event of renal failure.

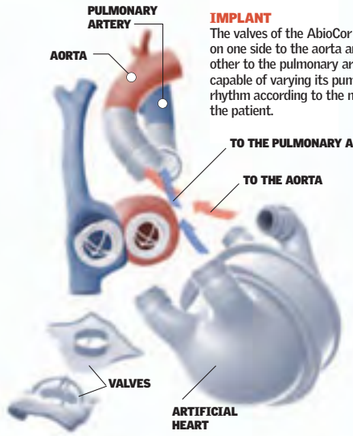
ARTIFICIAL LUNG
It consists of an intravenous device that permits breathing. It is inserted in a vein in the leg and is later positioned inside the vena cava, the largest vein for blood return to the heart. Fibrous membranes introduce oxygen into the body and remove carbon dioxide from it. Although not intended for prolonged use, it helps provide information that can guide future studies.

Machines of Life

There are currently machines that can replace damaged bodily functions. Scientific developments and advances in bionics have created devices that can functionally replace organs with great effectiveness. The successful development of these machines has allowed organ activity to be restored in patients who would otherwise have lost it forever. The clear disadvantage of these devices, however, is that the patient must be permanently attached to the machine in order to avoid any risk. To overcome this limitation, organ transplants are being sought more and more frequently. The latest medical advancements led to the creation of artificial organs, such as the artificial lung and heart, which can perform essential functions of a patient's body without requiring him/her to be connected to a bulky machine.

Artificial Heart

AbioCor was a milestone in the development of the artificial heart. Unlike its predecessor, the Jarvik-7, AbioCor is the first mechanical heart that can be totally self-contained in the patient's body. It functions almost exactly the same as a natural heart. It has two ventricles and two valves that regulate blood circulation. The AbioCor heart is powered without the need for cables or tubes that pass through the patient's body.



IMPLANT
The valves of the AbioCor connect on one side to the aorta and on the other to the pulmonary artery. It is capable of varying its pumping rhythm according to the needs of the patient.

HISTORY OF THE ARTIFICAL HEART

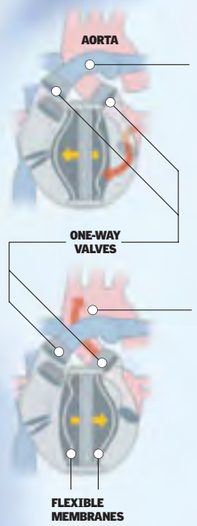
1 JARVIK-7
Robert Jarvik designed the first artificial heart, which was placed inside a patient in 1982. The Jarvik-7 functioned with an external air compressor, which provided power.

2 ABIOCOR
Unlike its predecessor, the AbioCor does not require an external power source. It was the first artificial heart to be fully implanted into a patient. It is still being developed, and scientists are attempting to extend its useful life to five years. It has already been authorized for use in the United States.

Heart 2006

The AbioCor heart was designed especially to support a patient's circulatory system and to prolong the lives of people who would otherwise die from cardiovascular failure. The heart, developed by Abiomed, is completely implantable in the body.

PUMPING SYSTEM
The heart developed by Abiomed is based on a hydraulic pump located at the center. Powered by a battery, the artificial heart reproduces the natural heart's performance almost identically. The deoxygenated blood goes to the lungs, and the oxygenated blood goes to the body.



1 TO THE LUNGS
The blood lacking in oxygen flows to the lungs. It is pushed by a hydraulic pump and two membranes.

2 TO THE BODY
The oxygen-rich blood flows to the body. A cardiac rhythm is established to pump the blood according to the needs of the patient.

Abiocor Heart
is made up of two ventricles with valves. Each ventricle pushes 2 gallons (8 l) of blood a minute and emits 100,000 beats in a day. The right ventricle pushes the blood toward the lungs, and the left one pushes it toward the rest of the vital organs and the body. The operation of the mechanical heart replicates that of a natural heart. It is made of titanium and plastic.

WITHOUT INCISIONS
The transcutaneous energy transfer (TET) system allows the battery to transfer energy to an internal battery through the skin. This way, potential infections caused by maintaining an opening in the abdomen are avoided.

INTERNAL BATTERY
recharges directly from the external battery. It allows the patient a certain degree of autonomy, since it can run for an hour and a half without needing to connect to the external battery at the waist.

CONTROL SYSTEM
regulates the rhythm with which the artificial heart pumps the blood. Depending on the needs of the patient, it can be increased or decreased. The internal control system is an electronic device capable of detecting any type of anomaly and making it known so that the patient can act on it.

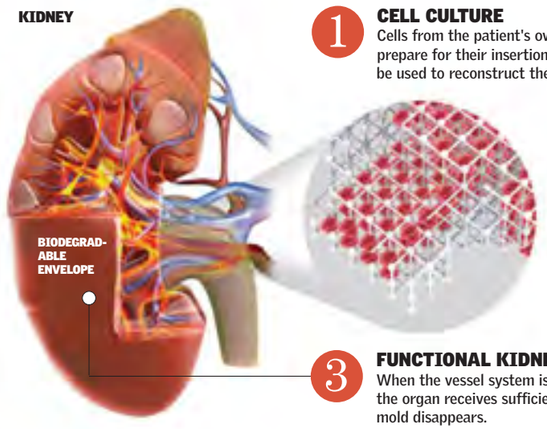
EXTERNAL BATTERIES
prevent the use of tubes, and the patient does not have to be immobilized. This source of power eliminates the need to connect to external machines to recharge the batteries. The device is worn at the waist and is portable.

Nanomedicine

The prefix "nano" indicates the scale on which the latest scientific developments are taking place: one billionth of a meter. From nanotechnology, advances have appeared in what is called nanomedicine. The main objective of this variant of nanotechnology is to obtain cures for diseases from inside the body and at a cellular or molecular level. Devices smaller than the diameter of a human hair have even been developed.

Nano-scaffolds for Regenerating Organs

The latest developments regarding the possibility of creating organs starting from a patient's own cells have demonstrated that by 2014 it may be possible to obtain a natural kidney simply through cellular regeneration rather than through a transplant. Beginning with biodegradable nanomolds, different organs could be created. The latest developments were able to produce a regenerated bladder in 1999. After being created, it was implanted successfully in seven patients. The procedure was done by doctor Anthony Atala of Wake Forest University. A section of a kidney that secretes a substance similar to urine has already been produced. Millions of nephrons still need to be regenerated, however, to achieve a fully functional kidney.



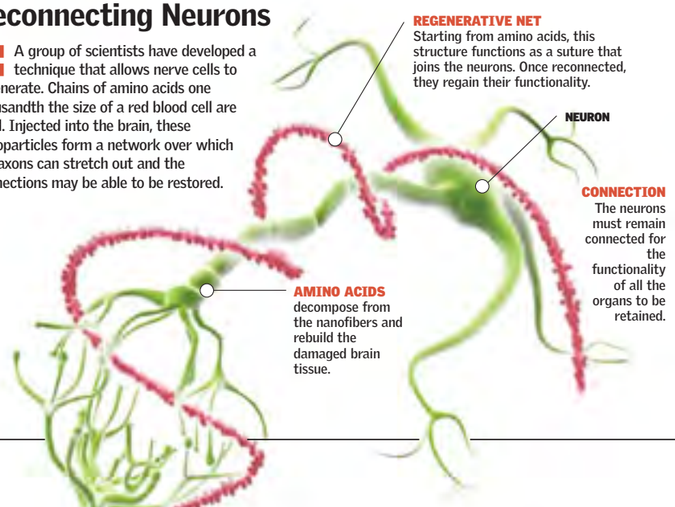
1 CELL CULTURE
Cells from the patient's own kidney are taken to prepare for their insertion into the mold that will be used to reconstruct the organ.

2 MOLD
A biodegradable mold is made in the shape of the kidney, in which the cells will be implanted and begin to grow. Then the blood vessels that will feed the organ will begin to develop.

3 FUNCTIONAL KIDNEY
When the vessel system is completely developed and the organ receives sufficient blood, the biodegradable mold disappears.

Reconnecting Neurons

A group of scientists have developed a technique that allows nerve cells to regenerate. Chains of amino acids one thousandth the size of a red blood cell are used. Injected into the brain, these nanoparticles form a network over which the axons can stretch out and the connections may be able to be restored.



Nanotechnology

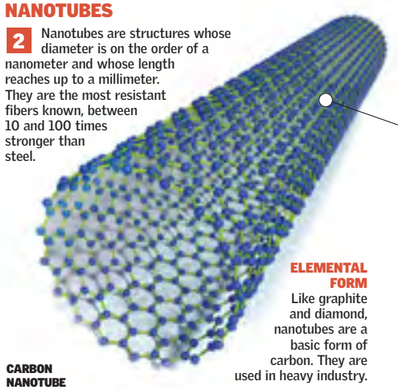
By working at the scale of a nanometer (10^{-9} meters), nanotechnology can currently be used in numerous areas of electronics, optics, and biomedicine. This state-of-the-art development builds devices so small that they can only be measured on the molecular scale. Today the most important and safest advances are the nanodevices used to detect cancer in its early stages. The nanoparticles can be between 100 and 10,000 times smaller than a human cell. Their size is similar to that of the larger biological molecules, such as enzymes. Nanoparticles smaller than 50 nanometers can easily enter any cell, while those smaller than 20 nanometers can move outside the blood vessels and circulate throughout the body.

MICROSCOPIC MOTOR

1 Smaller in diameter than a hair and 100 times thinner than a sheet of paper, micromotors are the basis for tiny machines that could travel through the body and destroy tumors or bacteria in their paths.

NANOTUBES

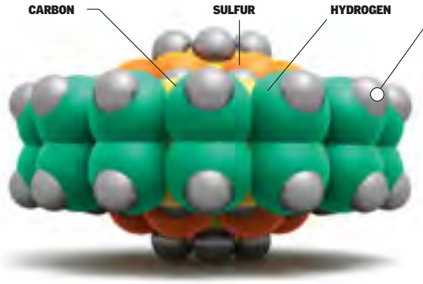
2 Nanotubes are structures whose diameter is on the order of a nanometer and whose length reaches up to a millimeter. They are the most resistant fibers known, between 10 and 100 times stronger than steel.

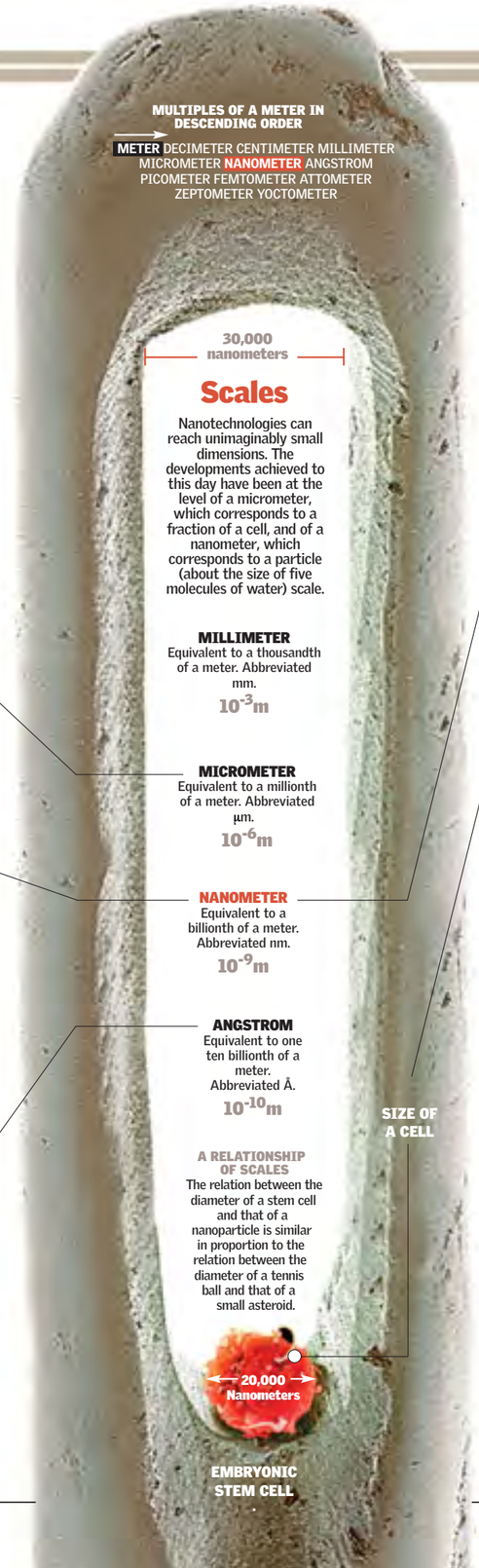


ELEMENTAL FORM
Like graphite and diamond, nanotubes are a basic form of carbon. They are used in heavy industry.

NANOTECHNOLOGIC MOLECULE

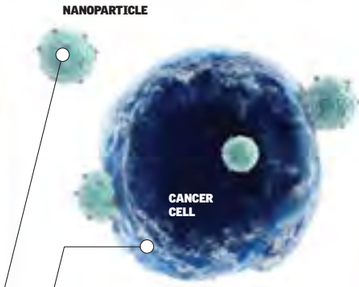
3 Each sphere of the molecule represents an atom: carbon in yellow, hydrogen in green, and sulfur in orange. It is based on fullerenes.



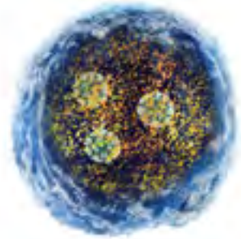


Nanoparticles

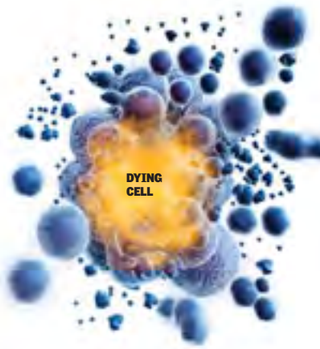
The use of nanoparticles to combat diseases such as cancer has been carried out successfully in rats by scientists Robert Langer and Omid Farokhzad. The nanoparticles are one thousandth the size of the period at the end of this sentence. They are made up of carbon polymers that directly attack the cancer cells and destroy them without harming surrounding healthy cells. They act like guided missiles. This approach would make it possible to surpass the complications of chemotherapy. It is estimated that its full development will be complete in 2014.



1 NANOSHIELDS
The small carbon "bombs" detect the cancer cells and go directly toward them. They adhere to the tumor and prepare for their second phase: unloading.



2 UNLOADING
Once the nanoparticles have entered the tumor, they release their carbon load, which contains instructions to destroy the cell.



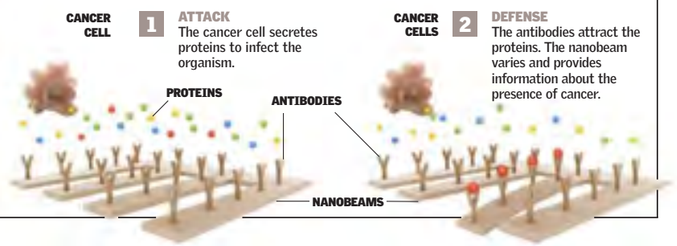
3 EXPLOSION
The attacked tumor cells are destroyed, and they die. Unlike chemotherapy, the surrounding healthy cells are not harmed.

NANOPARTICLES AND CELLS
To understand the scale at which nanoscopy works, we can compare the particles involved: a nanoparticle is to a cell what a grain of sand is to a football stadium.

A GRAIN OF SAND **IN A FOOTBALL STADIUM**

Nanoscopic Beams

Small microscopic and flexible beams that are built with semiconductors using lithographic techniques. These beams are covered with molecules capable of adhering to specific DNA. If a cancer cell secretes its molecular products, the antibodies placed on the flexible beams will bind to the secreted proteins. This generates a change in the physical properties of these beams, and researchers can read and interpret this information in real time.

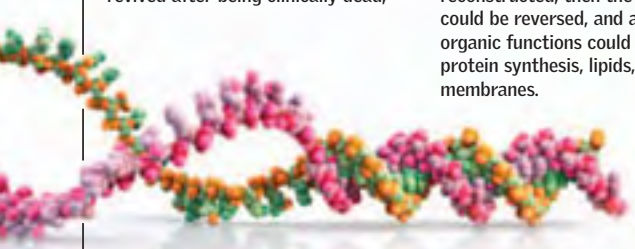


En Route to Eternity

The dream of an eternal body seems to dominate scientific study today. The possibility of building a nerve system from a network of cables, proposed through developments in neuroscience, and the building of metallic muscle systems are two examples of steps that are being taken in that direction. According to some specialists, the future promises the creation of a bionic body, without ties to flesh. In this scenario, every health problem could be solved though metallic implants. There is even a study that explores the possibility of repairing DNA after cell death to assure the eternal youth of cells. ●

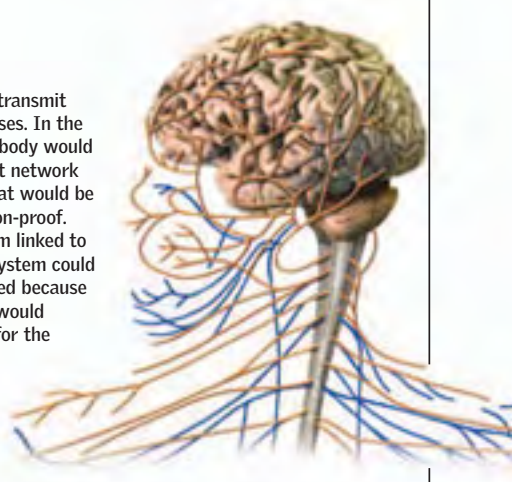
DNA Repair

Biologist Miroslav Radman discovered that the bacteria *Deinococcus radiodurans* can be revived after being clinically dead, through the repair of its DNA. If DNA could be copied rapidly and the genome of dead human cells could be reconstructed, then the death of cells could be reversed, and all their organic functions could be restored: protein synthesis, lipids, and membranes.



Self-Healing Cells

The dream of having a body in which there is no degeneration of nerve cells is on its way to becoming a reality: neuroscientist John Donoghue of Brown University is trying to re-create the nervous system through optical fibers. These fibers would be used to transmit brain impulses. In the future, the body would be a perfect network of fibers that would be degeneration-proof. Any problem linked to the nerve system could be eliminated because the cables would substitute for the nerves.



Artificial Organs

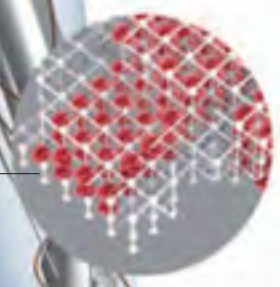
Today efforts continue to design artificial organs that could replace organs that have been damaged or affected by severe diseases. By 2008, the Abiomed company plans to have the AbioCor heart developed to perfection. Although initial trials have been unsuccessful, Abiomed plans to design a heart that lasts for at least five years. Even so, it is very expensive: at least $100,000.

ABIOCOR HEART

4,000
The number of stem-cell transplants worldwide

Organ Regeneration

Anthony Atala of Wake Forest University is the leading pioneer of organ-regeneration research. In 1999, he was able to re-create a bladder from cells extracted from other tissue. Atala and his team estimate that by 2014 great advancements will have occurred in the regeneration of the most complex organ: the kidney. Once a kidney can be regenerated, transplants and artificial organ implants will become a thing of the past.



MRI OF THE BRAIN

TUMOR
A meningioma appears in the magnetic resonance image. It can be removed with surgery.

200 years
is predicted to be the estimated life expectancy by the 22nd century.

NANOPARTICLES
A thousand times smaller than a period drawn with the tip of a pencil, the molecule that could defeat cancer without the need for chemotherapy is a carbon polymer.

INVASION
Once it has detected a cancer cell, the nanoparticle penetrates it and unloads its carbon. The sick cell is destroyed.

Scan of the Body

The images obtained from magnetic resonance imaging (MRI) permit exploration of the body in 360 degrees. The most extensive use of MRI, however, is in the complete scanning of the brain to obtain a variety of images, which permits doctors to observe both the surface and the inside of the brain. Magnetic resonance imaging is one of the most commonly employed medical techniques for obtaining accurate images of the different organs of the body. Its resolution capability permits even the scanning of tissues.

Cancer

If the studies by Robert Langer of the Massachusetts Institute of Technology (MIT) and Omid Farokhzad of Harvard University prove to be beneficial, chemotherapy will become a thing of the past. By using particles the size of amino acids (nanoparticles), cancer cells could be eliminated without harming the healthy cells located near them. Like guided missiles, the molecules go directly to the infected cells. Carbon polymers have been successfully tested in rats to eliminate the cancerous cells by penetrating them and injecting their content. Tests are still in development, and scientists estimate that by 2014 it will be possible to apply these new drugs.

SIZE
The required sample is as small as a postage stamp.

CULTURE
The creation of new cells takes place in a plastic container with a gel that provides nutrients for the epithelial cells.

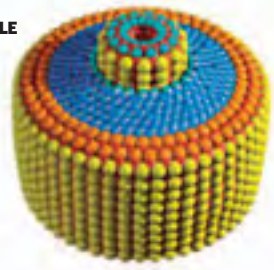
NEW SKIN

PLASTIC CONTAINER

Graft

The latest skin grafts are called autografts. They can save lives after severe injuries suffered by serious burn victims. From a small sample of healthy tissue, damaged tissue can be regenerated in three weeks through a cell culture.

NANOPARTICLE



60,000
nanometric molecules would be necessary to cover the diameter of a human hair. Building devices at this level could speed up all kinds of treatment.

Bionic Limbs

In 2005, the Rehabilitation Institute of Chicago performed the implantation of an artificial arm controlled by the brain. The University of Texas has been investigating an elastic metal that could replace natural muscles. The artificial muscular system is 100 times stronger and more resistant than human tissue. If these developments work out, they would provide a way of successfully replacing damaged joints.

Glossary

Agonist

Chemical product that, in addition to combining with a receptor (such as an antagonist), stimulates it, producing an observable effect. The term is also applied to a muscle that carries out a specific movement.

Allele

Variation of a gene in the population that codifies a specific trait. A diploid cell contains an allele from each parent for each characteristic.

Allergen

Substance or material capable of provoking an allergic reaction.

Alzheimer's Disease

A specific type of breakdown of the nervous system that causes cognitive disorders. It is related to advanced age.

Angiogenesis

Growth (normal or abnormal, depending on the circumstances) of new blood vessels in an organ or tissue.

Antagonist

Substance that inhibits or interferes with the action of other substances (hormones or enzymes). The term is also applied to muscles that, in the same anatomical region, act in opposite directions.

Antibiotic

Medicine that kills certain microorganisms or that impedes their growth and spread. It is used to treat infections.

Antigen

Substance that, when introduced into an animal body, results in defense reactions, such as the formation of antibodies.

Aorta

The largest artery in the body, it starts in the left ventricle of the heart. It is called the thoracic aorta until it reaches the diaphragm, and below that it is called the abdominal aorta, where it later bifurcates into the iliac arteries.

Arterial Hypertension

Elevated blood pressure, above 140 millimeters of mercury (systolic) and above 90 mm (diastolic).

Artery

Each one of the blood vessels through which the blood travels from the heart to supply the whole body.

Arthritis

Inflammation of the joint that could be the result of several causes.

Atherosclerosis

The accumulation of lipids (especially cholesterol) in the internal walls of the arteries; one of the main causes of diseases of the circulatory system.

Autonomous Nervous System

Part of the nervous system that regulates involuntary processes (heart rhythm, pupil dilation, stomach contractions, etc.). It includes the sympathetic and parasympathetic systems.

Bacterium

Microscopic organism that divides in two to reproduce. There are bacteria that are innocuous, pathogenic, and even beneficial to the human body.

Blastocyst

Cell mass, resulting from the division of the morula, that gives rise to the embryo.

Calcification

Fixation of calcium, an essential trace element for the formation of bones.

Cancer

Disease caused by the appearance and uncontrolled growth of a mass of abnormal tissue (malignant tumor).

Cell Membrane

Flexible envelope of all living cells that contains the cytoplasm. The membrane regulates the exchange of water and gases with the exterior.

Central Nervous System

Structure made up of the brain and the spinal cord.

Cerebral Cortex

Made up of gray matter present on the surface of the brain. It is the largest part of the central nervous system. Many of the most advanced functions take place in this cortex.

Cholesterol

Unsaturated lipid found in the body's tissues and in blood plasma. It is also found in elevated concentrations in the liver, spinal cord, pancreas, and brain. Cholesterol is ingested through some foods and is synthesized by the liver, then passed to the blood as HDL cholesterol, considered protective, or as LDL cholesterol, which in excess leads to the development of atherosclerosis.

Chromosome

Structure that carries the genes. These exist in the nucleus of each eukaryotic cell.

Cilia

Small cellular appendages shaped like hairs and used for locomotion in a liquid medium.

Conception

The union of a sperm with an egg.

Cytoplasm

Compartment in eukaryotic cells surrounded by the cell membrane.

Dermatophytosis

Infection in the skin caused by some species of fungi.

Diabetes

Chronic disease characterized by elevated levels of blood glucose due to metabolic disorders.

DNA

Deoxyribonucleic acid. Organic molecule with the shape of a double helix that contains the coded genetic information of an individual.

Dominance

Functional attribute of the genes by which they manifest their effect, regardless of the effect of the allele that accompanies them.

Embryo

Product of fertilization of the egg by a sperm; it can develop into an adult organism.

Endoplasmic Reticulum

Organelle made up of a network of membranes that joins the nucleus of a cell to the Golgi complex. Protein synthesis takes place in it.

Enzyme

Protein that helps to regulate the chemical processes of a cell, usually triggering or accelerating a reaction.

Erythrocytes

Red blood cells; they carry oxygen.

Estrogens

Female hormones produced by the ovaries and by the adrenal glands. They stimulate the growth of cells in the endometrium, the ovaries, and the breasts.

Fetus

The human body in gestation, after the third month and until birth.

Flagellum

Filament-like structure that is found on some bacteria and is used for locomotion.

Follicle

Sac-shaped gland located in the skin or in the mucous membranes.

FSH

Follicle stimulating hormone. Female hormone involved in the ovulation process.

Fungus

Live unicellular or multicellular organism belonging to the Fungi kingdom.

Gene

Information unit of a chromosome; the sequence of nucleotides in a DNA molecule that carries out a specific function.

Genome

The entire complex of chromosomes and their genes; the totality of the genetic material in a cell or individual.

Genotype

Genetic constitution of a single cell or an organism with reference to a single characteristic or set of characteristics; the sum of all the genes present in an individual.

Graft

Implantation into an organism of a portion of live tissue that comes from another organism or another part of the same one. Also, the portion of tissue to be implanted.

Hemoglobin

Protein (globin) associated with a porphyrin that contains iron (heme group) and is found inside the red blood cells; it transports oxygen.

Hormone

Product of gland secretion, its function is to stimulate, inhibit, or regulate the action of other glands, systems, or organs of the body.

Immune System

Set of processes centered on the blood and the lymphatic system that is activated to defend the human body against diseases.

Insulin

Hormone secreted by the pancreas that is responsible for the metabolism of glucose in the body.

Ion

Atom of an element or a molecule that is electrically charged because it has gained or lost electrons from its normal configuration.

Joint

The area where a bone or a skeletal organ comes together with another.

Laser

From the acronym for Light Amplification by Stimulated Emission of Radiation, it is a luminous artificial emission of variable frequency. Its energy can be controlled because of the coherence of its beams.

Leukocyte

White blood cell. A component cell of the blood, its main function is to defend the body from infectious agents.

Lipids

Organic chemical compounds formed mostly by hydrogen and carbon. Cholesterol and edible oils are the best known.

Lymph

Liquid that moves through the lymphatic system.

Lymphatic System

Ensemble of lymphatic vessels and ganglia that is independent of blood flow. It acts as a regulator of osmotic equilibrium in the body and as an activator of the immune system.

Lymphocyte

Belongs to the group of white blood cells. It is present in the blood and in the lymphatic system.

Lymphoma

Neoplastic disease that originates in the lymphatic system.

Meiosis

Type of cell division in which two successive cell divisions of the nucleus of a diploid cell result in four haploid nuclei. As a result of this mechanism, gametes or spores are produced.

Metabolism

Set of chemical reactions that are constantly carried out by cells to synthesize complex substances from simpler ones or to degrade the former to obtain the latter, as in the digestive process, for example. The activity level of body functions at rest and while fasting is called basal metabolism.

Metastasis

Spreading of a cancerous tissue, making it capable of attacking organs other than the one from which it originated.

Mitochondria

Organelle that is bounded by a double membrane. Within the mitochondria, ATP is obtained from the decomposition of sugars and other substances—the final step in aerobic respiration.

Mitosis

Division of a cell in which two identical cells are formed from the parent cell.

Morula

Early stage in the development of a multicellular organism, made up of 16 to 64 cells. It gives rise to the blastocyst.

Mycosis

Infection caused by fungi.

Nanotechnology

Industrial technology that permits the fabrication of microscopic devices.

Neurotransmitter

Chemical substances responsible for the transmission of the nerve impulse through the neuron synapses.

Nucleus

Part of the cell inside the cytoplasm. The nucleus contains almost all the DNA in a cell.

Osmosis

Diffusion of water through a semipermeable membrane.

Ovulation

Release of the mature egg from the ovary through the fallopian tube.

Oxyhemoglobin

Hemoglobin of arterial blood that is loaded with oxygen.

Oxytocin

Female hormone produced by the hypothalamus, it is transported to the hypophysis and is later released into the bloodstream. In women, it is responsible for, among other functions, the milk-ejection reflex and uterine contractions.

Parkinson's Disease

Neurological disorder caused by a deficit of the neurotransmitter called dopamine.

Pectoral Angina

Oppressive pain located in the retrosternal region, caused by an insufficient flow of oxygenated blood to the cardiac muscle.

Phenotype

Physical expression of a genotype.

Platelet

Cellular component of blood that takes part in the clotting process.

Progesterone

Female hormone involved in the menstrual cycle and gestation.

Protein

Substance that makes up parts of the cells. It is formed by one or more chains of amino acids and is fundamental to the constitution and functioning of the essentials of life, such as enzymes, hormones, and antibodies.

Protozoa

Microscopic, unicellular, heterotrophic organisms that live in an aqueous medium and that reproduce through bipartition.

Reflex

Automatic and involuntary reaction of the nervous system that is produced in response to a stimulus.

Ribosome

An organelle located in the cytoplasm, it directs the formation of proteins based on the information given by the nucleic acids.

RNA

Ribonucleic acid, similar to DNA but used to transport a copy of the DNA to the ribosome, where proteins are manufactured.

Saturated Fats

Fats of animal origin that are involved in nutrition.

Schwann Cells

Cells that produce myelin, a fatty insulating substance; it covers the nerve fibers that keeps the electrical signals from losing speed as they get farther away from the body of the neuron.

Semen

Combination of sperm and liquid substances produced in the male genital system.

Somatotropin

Human growth hormone, secreted by the pituitary gland (hypophysis).

Spirillum

Flagellated bacterium with a helical or spiral form.

Spore

Reproductive cell of a fungus.

Sugar

Generic name of the organic chemical compounds known as carbohydrates.

Synthesis

Chemical process in which two or more molecules join to produce a larger one.

Systemic

Describes a disorder that affects several organs or the body as a whole.

Testosterone

Androgenic hormone related to the primary as well as secondary male sexual traits. It is produced by the testicles and to a lesser extent by the adrenal glands and ovaries in women.

Thrombus

Solid mass of blood formed inside a vein or artery. If it travels through the circulatory system, it is called an embolus, which can cause an obstruction.

Tissue

Group of identical cells that carry out a common function.

Transcription

Copying of the genetic code of the DNA into another molecule, such as RNA.

Transplant

Insertion of live tissue into a living organism from another organism (living or not).

Tumor

Any alteration of the tissues that produces an increase in volume.

Vagus Nerve

Also called the pneumogastric nerve, it is the 10th of the 12 cranial pairs. It originates in the brainstem and innervates the pharynx, esophagus, larynx, trachea, bronchia, heart, stomach, and liver.

Vein

Each one of the blood vessels that take deoxygenated blood to the heart.

Vibrio

Genus of elongated bacteria in the shape of a comma with a single cilium, such as the one that produces cholera.

Virus

Organism at the boundary between living and inert. It can be potentially pathogenic, and it can consist of a protein capsule (capsid) that surrounds the genetic material (DNA or RNA).

Vitamin

One of the organic substances that ensures the equilibrium of vital functions and constitution of the tissues. They are designated with the letters of the alphabet.

Zona Pellucida

Envelope that protects the egg; the sperm must negotiate it during fertilization.

Zygote

The diploid cell formed by the union of the sperm and the egg after fertilization; also called the ovum.

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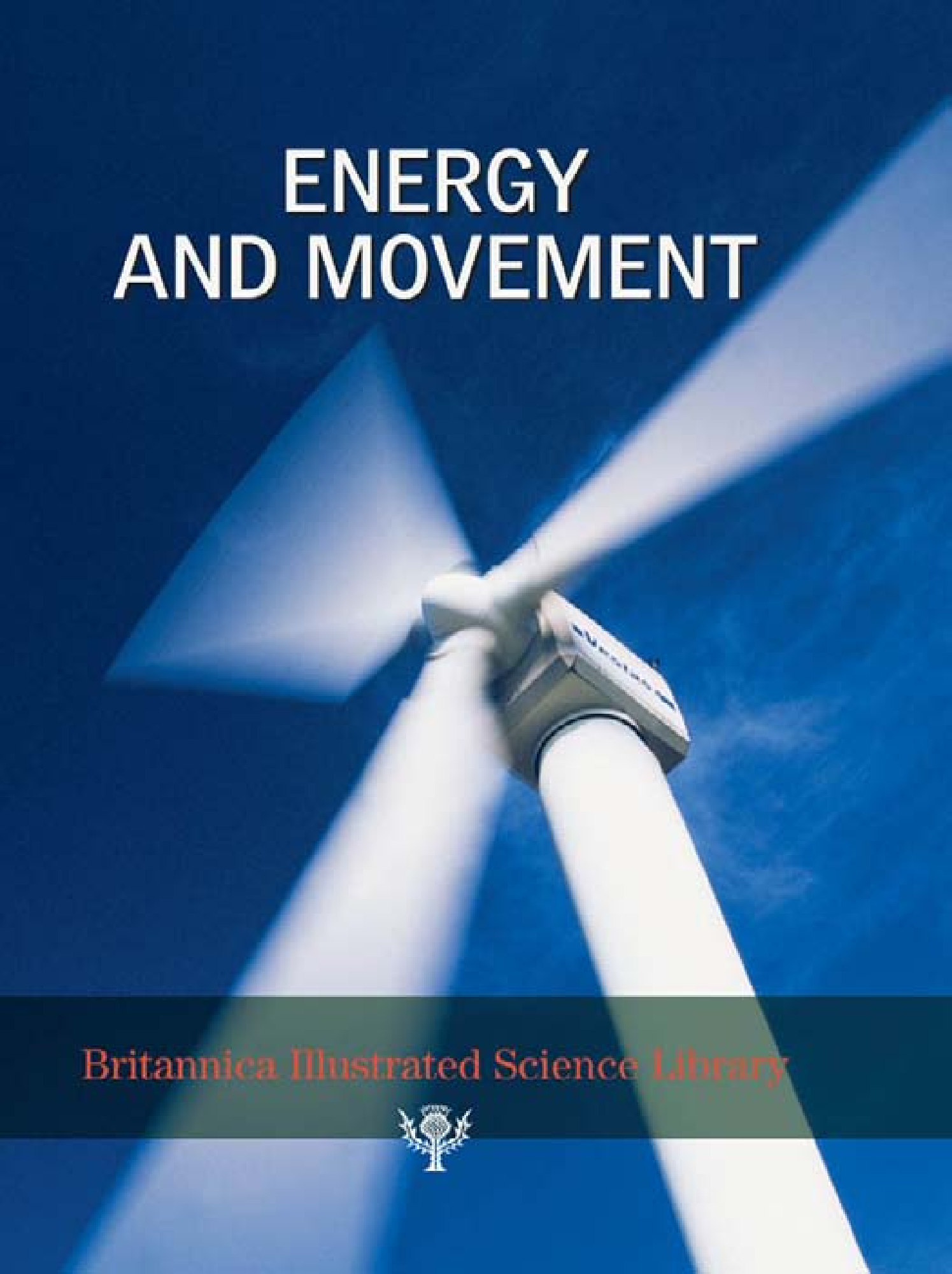

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The Source of Change

ONE GIANT SOURCE OF ENERGY
Our star, the Sun, is a huge nuclear reactor where each second more than four tons of matter are transformed into energy equivalent to almost 92 billion megatons of TNT.

We use the word "energy" daily to refer to different things. We are told, for instance, that certain food does not provide sufficient energy; we are told about the exploitation of energy resources; or we are warned by the politicians about the energy crises. When we are tired, we have "no energy." We also hear about alternative sources of energy and the mention, by some religions and pseudosciences, of spiritual energy—and so on. But what is energy? In general, and in the sense used in this book, energy is "the potential to produce change," the capacity to act, transform, or set in motion. Other accepted meanings that we will use refer to energy as a natural resource and as the technology associated with exploiting and using the resource, both industrially and economically.

The development of steam engines during the Industrial Revolution generated the need for engineers to develop formulas and concepts to describe the thermal and mechanical efficiencies of the systems they were developing. Thus, they began speaking about "energy." Energy is an abstract physical quantity. This means that it cannot be measured in a pure state but that only variations of energy in material systems can be observed. These variations are equivalent to the work required to change one system from its initial state to a subsequent one. Energy cannot be created or destroyed; it can only be transformed from one form to another. Obviously there are forms of energy that can be transformed or used more easily than others and, in the end, all forms of energy will become heat energy, one of the most disordered forms of energy. This loss of energy in the form of heat results in machines and human-developed processes working with less than the 100 percent efficiency one would expect if one were to apply the principle of the conservation of energy literally.

However, as already mentioned, there is also another definition of the word "energy" that refers to the natural resources necessary to produce energy as engineers and physicists understand it. This understanding of energy is very important and affects us all. Its role in the global economy is essential, and it could be said that most recent wars have had as one of their goals the control of energy resources—both renewable and nonrenewable.

In this book, we present some of the most important sources of energy used by humanity. We show how human ingenuity has been able to put the different forms of energy at its service by developing machines of all kinds, and we describe some of the most important manifestations of energy in the natural world. We also dedicate a chapter to describe the uses of clean, renewable sources of energy, including solar, wind, water, and geothermal sources. Finally, we list some of the inventions that people throughout history have developed to satisfy their instinct to explore. These are inventions that made people move faster and travel farther with less and less energy. The progression from animal-driven transportation to steam engines and internal-combustion engines is a key to understanding modern civilization.

Origin and Sources

AMUAY REFINERY
This petroleum refinery is one of the largest in the world. It is located in the state of Falcón in Venezuela.

SOURCES OF ENERGY 8-9
MATTER 10-11
THE ATOM 12-13
ELECTRICITY 14-15

Because energy can take on many forms, there are many possible sources from which we can generate both work and heat. Some of these sources, such as the Sun or the atom, are the very reasons for our existence, and it could almost be said that the other forms of energy are derived from them. Others, such as natural gas, petroleum (oil), or coal, are the result of geologic processes that have taken billions of years to complete. Some of these sources are renewable, but others run the risk of being exhausted if we do not use them wisely. The truth is that we find ourselves in a time when we must rethink our habits of energy usage.●

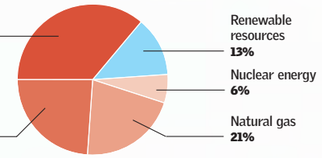
Sources of Energy

Energy is vital to life. From it, we get light and heat, and it is what allows economic growth. Most of the energy we use comes from fossil fuels, such as petroleum, coal, and natural gas—substances that took millions of years to form and that will someday be depleted. For this reason, there are more and more countries investing in technologies that take advantage of clean, renewable energy from the Sun, wind, water, and even the interior of the Earth. ●

Nonrenewable Sources

These are the sources of energy that are limited and can forever be depleted through use. They represent up to 85 percent of the world's energy consumption and form the basis of today's insecure energy economy. These nonrenewable sources of energy can be classified into two large groups: fossil fuels (coal, petroleum, and natural gas) and nuclear energy, which is produced in nuclear power plants from uranium—a scarce, controlled radioactive material.

PRIMARY GLOBAL ENERGY SOURCES



Percentages are for the year 2003

NATURAL NUCLEAR REACTOR
The solar energy absorbed by the Earth in a year is equivalent to 20 times the energy stored by all the fossil-fuel reserves in the world and 10,000 times greater than the current consumption of energy.

Renewable Sources

Renewable energy resources are not used up or exhausted through use. As long as they are used wisely, these resources are unlimited because they can be recovered or regenerated. Some of these sources of energy are the Sun, the wind, and water. Depending on the form of exploitation, biomass and geothermal energy can also be considered renewable energy resources.

C HYDROELECTRIC ENERGY
is generated by turbines or water wheels turned by the fall of water. Its main drawback is that the construction of reservoirs, canals, and dams modifies the ecosystems where they are located.

D SOLAR ENERGY
The Sun provides the Earth with great quantities of energy, which can be used for heating as well as for producing electricity.

E WIND ENERGY
ultimately comes from the Sun. Solar radiation creates regions of high and low pressure that creates currents of air in the atmosphere. Wind is one of the most promising renewable energy resources, because it is relatively safe and clean.

F GEOTHERMAL ENERGY
is produced by the heat in the crust and mantle of the Earth. Its energy output is constant, but power plants built to access it must be located in places where water is very close to these heated regions.

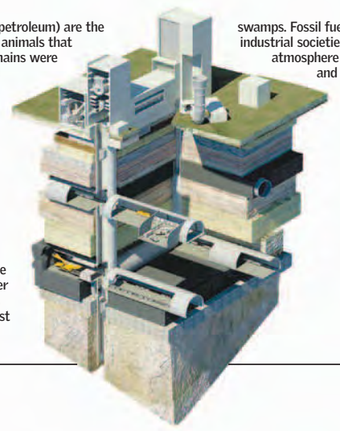
G HYDROGEN ENERGY
The production of hydrogen is a new and, for the moment, costly process. But, unlike other fuels, hydrogen does not pollute.

H RENEWABLE CHEMICAL ENERGY BIODIGESTERS
produce fuel from biological resources, such as wood, agricultural waste, and manure. It is the primary source of energy in the developing regions. The methane gas it produces can be used for cooking or to generate electricity.

I TIDAL ENERGY
is one of the newer forms of producing electrical energy. It harnesses the energy released by the ocean as its rises and falls (the ebb and flow of tides).

B NUCLEAR ENERGY
One of the methods of obtaining electrical energy is through the use of controlled nuclear reaction. This technology continues to be the center of much controversy because of the deadly wastes it generates.

A FOSSIL CHEMICAL ENERGY
Fossil fuels (coal, natural gas, and petroleum) are the result of the sedimentation of plants and animals that lived millions of years ago and whose remains were deposited at the bottom of estuaries and swamps. Fossil fuels are the main source of energy for industrial societies. Their combustion releases into the atmosphere most of the gases that cause acid rain and the greenhouse effect.



THERE COULD BE NO MORE COAL RESERVES AFTER THE YEAR
2300.

COAL
Coal drove the Industrial Revolution in the developed world. It still provides a quarter of the world's commercial energy. Coal is easy to obtain and use, but it is the dirtiest of all energy resources.

GAS MIGHT RUN OUT IN THE YEAR
2150.

NATURAL GAS
Formed by the breakdown of organic matter, it can be found in isolation or deposited together with petroleum. One way of transporting it to places of consumption is through gas pipelines.

PETROLEUM WILL RUN OUT IN THE YEAR
2050.

PETROLEUM
Petroleum is the most important energy resource for modern society. If it were to suddenly be depleted, it would be a catastrophe: airplanes, cars, ships, and thermal power plants, among many other things, would be inoperable.

J BIOFUEL ENERGY
The most common biofuels are ethanol and biodiesel, which are produced from conventional agricultural products, such as oilseeds, sugarcane, or cereals. In the future, they are expected to partially or completely replace gasoline or diesel.

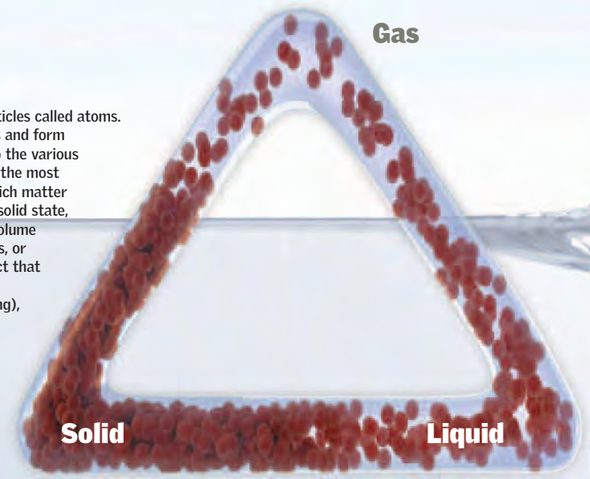
21%
PERCENT OF "GREEN" ELECTRICITY THAT EUROPE PLANS TO USE IN 2010

Matter

The dictionary says that matter is everything that takes up space. In other words, whatever makes up a substance in the physical universe—the Earth, the seas, the Sun, the stars—is matter. Everything that humans see, touch, or feel is matter. Matter can be hard as steel, adaptable as water, and shapeless as the oxygen in the air. The study of matter has permitted the fabrication of tools, construction of cities, and even flights into space. Regardless of what is currently known about it, the more scientists look into matter, the more complexity they find. For example, it is now known that not even the hardest diamond is really solid, because the atom—the heart of matter—is almost all empty space. ●

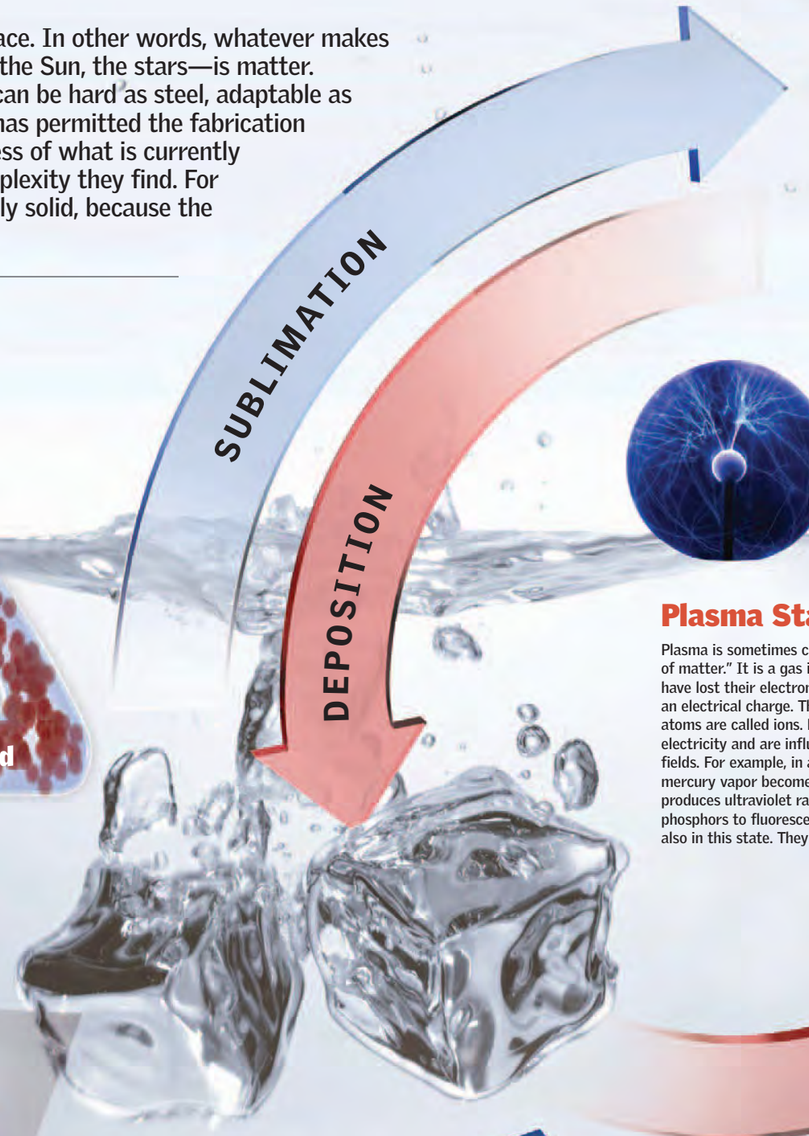
What Is Matter Made of?

Matter is made of small particles called atoms. The atoms group themselves and form molecules, which are arranged into the various forms of matter. In our daily lives, the most commonly recognized states in which matter exists are solid, liquid, and gas. In solid state, bodies have an almost invariable volume because their particles (atoms, ions, or molecules) are in such close contact that they can get no closer. When the temperature is high enough (melting), particles lose their fixed positions and, although they are still very close, the crystalline structures exclusive to solids disappear in changing to the liquid state. Above the boiling point, the particles lose contact with each other and move freely (gaseous state).



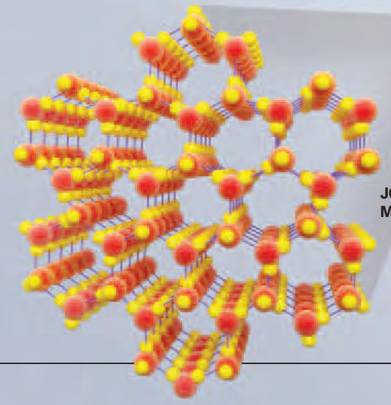
From the Solid State to the Gaseous

Ice and steam are the same substance as liquid water. The difference lies in the strength with which their molecules attract each other and the way in which they group themselves. Water molecules have the same shape and the same atoms in the three states. Water can change directly from ice to a gaseous state, but the process, called sublimation, occurs slowly at normal air pressure.



A Solid State

As a general rule, in solids the particles (atoms or molecules) are closer together than liquids. That is why the density of a solid substance is greater than in the liquid state. However, water is an exception. In other words, when water freezes, it expands and becomes lighter. Ice floats on water because of this process. When the temperature of a piece of ice increases, the molecules increase their vibration and their separation.

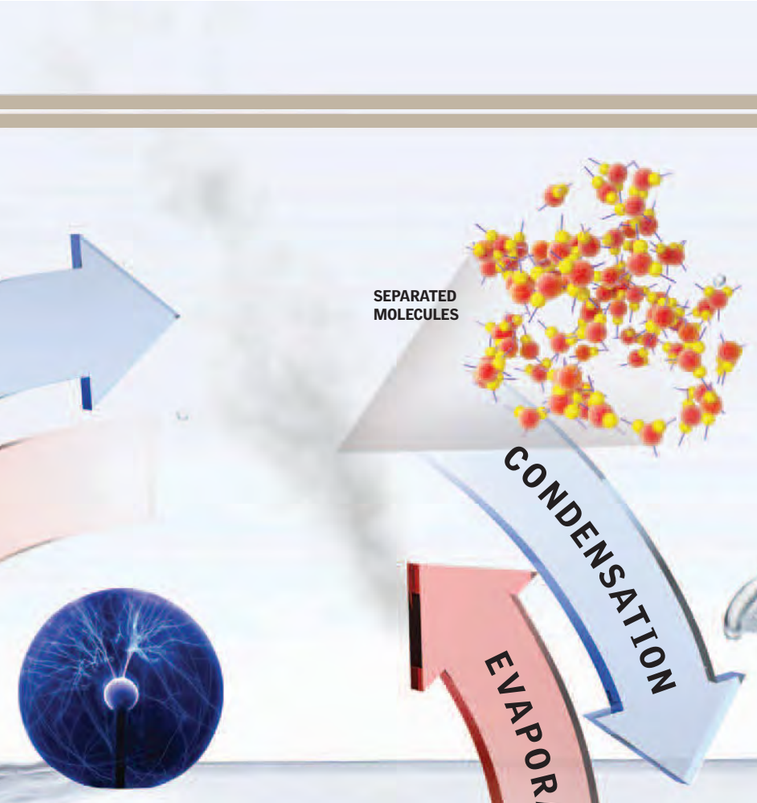


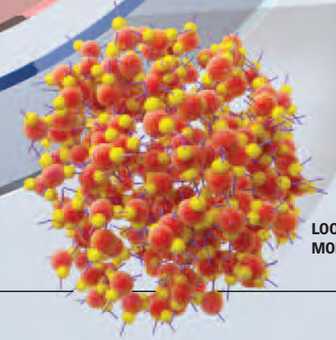
32° F (0° C)

Freezing point. The temperature at which water passes from the liquid to solid state.

Plasma State

Plasma is sometimes called "the fourth state of matter." It is a gas in which the atoms have lost their electrons and therefore have an electrical charge. The electrically charged atoms are called ions. Plasmas conduct electricity and are influenced by magnetic fields. For example, in a fluorescent bulb, mercury vapor becomes a plasma that produces ultraviolet radiation and causes phosphors to fluoresce. The Sun and stars are also in this state. They are not solids.





C Gaseous State

At various temperatures, molecules escape the surface of liquid water to form gas or steam. The change from gas to liquid state is called condensation, and the change from liquid to solid state is called solidification, or freezing. In other instances, there can be a direct change from solid to gas (sublimation) and from gas to solid (condensation).

B Liquid State

As in all liquids, water molecules tend to form groups. They can move over one another, allowing water to flow with ease. The variable form of liquids (which adjust to the containers that house them) results from the fact that, above the melting point, liquid particles do not stay in the fixed positions of a solid and instead move in a disordered fashion.

212° F (100° C)

Boiling point. The temperature at which water turns into vapor.

The Atom

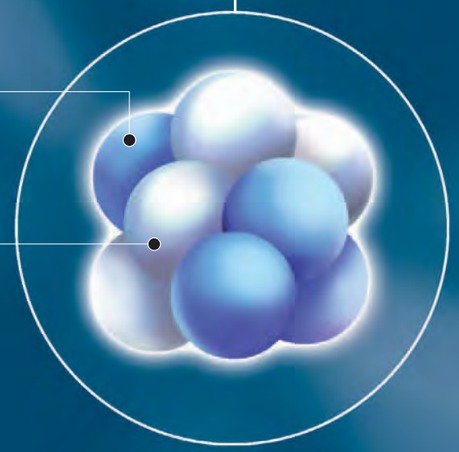
In physics and chemistry, an atom is the smallest unit of a chemical element that retains its identity and properties; it cannot be divided any further by chemical processes (it can, however, be divided by physical processes). All matter in the universe is made up of atoms. This concept originated in ancient Greece, but the existence of the atom was not demonstrated until the 19th century. The development of nuclear physics in the 20th century led to the discovery that the atom can be subdivided into various types of smaller particles.

Nucleus

determines the physical properties that distinguish one element from another. It contains most of the atom's mass (atomic weight).

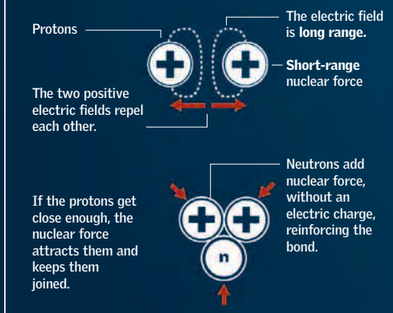
PROTONS
ELECTRICAL CHARGE: POSITIVE
ATOMIC WEIGHT: 1
The quantity of protons determines the chemical element to which the atom belongs. For example, if three protons are removed from a lead atom, a gold atom remains.

NEUTRONS
ELECTRICAL CHARGE: NEUTRAL
ATOMIC WEIGHT: 1
Helps hold the nucleus together.



How It Is Held Together

Because protons have positive charges, they repel each other. However, the atomic nucleus remains intact because of another force of greater magnitude, though of shorter range, known as the strong nuclear interaction.



History of the Atomic Theory

500 BC
ANCIENT GREECE
Democritus and Leucippus assert that matter is composed of tiny, indivisible particles that are in constant motion.

1808
JOHN DALTON
states that atoms of a same element measure and weigh the same but not those of a different element.

1869
DMITRY MENDELEYEV
organizes the elements according to their atomic weight in the so-called periodic table of elements.

1911
ERNEST RUTHERFORD
develops the first coherent model that explains the atomic structure. It was improved in 1913 by Niels Bohr.

1920
QUANTUM MECHANICS
sets the foundation for the discovery of atoms in the 20th century. In 1932, neutrons were discovered, completing the model.

ISOTOPES
The nucleus of a given element can have a variable number of neutrons without changing its fundamental nature. These variations of the same element have slightly different behaviors and are known as isotopes.

RADIOACTIVITY
Certain unstable isotopes decay over time, emitting particles and radiation.

IONS

If the number of electrons is equal to the number of protons, the atom is electrically neutral.

If the atom loses an electron, it transforms into a positive ion, or cation.

If it gains an extra one, it becomes a negative ion, or anion.

Invisible to the Microscope

The atoms cannot be seen through a microscope (either optical or electronic). Computational advancements have allowed us to obtain images of the position that atoms occupy in a substance, but the structure of each individual atom has not been imaged.

ATOMIC STRUCTURE

10 trillion

THE NUMBER OF ATOMS THAT CAN FIT ON THE SURFACE OF A PINHEAD

Electron Cloud

The electrons are found in the electron cloud. An electron has a negative electrical charge and an atomic weight of 0.0005434 amu. The electrons determine the chemical and electrical properties of elements, and they are involved in bonding with other atoms. Within the electron cloud, the electrons are distributed in orbits, or orbitals.

Electron Orbitals

RUTHERFORD-BOHR MODEL
(PLANETARY MODEL)
This model, which is obsolete, depicted electrons as planets that revolve around the nucleus. However, it is the model that persists in popular perception.

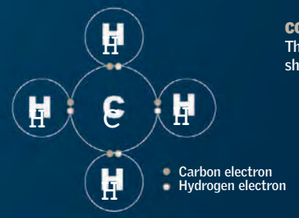
VALENCE SHELL MODEL
(QUANTUM MODEL)
The electrons are not in a fixed orbit but in regions of greater or lesser probability, and they can move in any direction within the region.

Quantum Leap

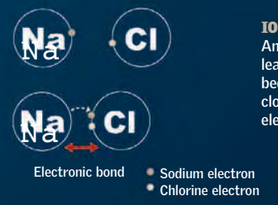
Niels Bohr discovered that electrons orbit the atom with discrete levels or quanta of energy—that is, not all orbitals are permitted but only a finite number. The electrons jump from one level to another in quantum leaps. If a jump is from a higher energy level to a lower one, a photon is released (emits light). If the jump is reversed, a photon is captured (absorbs light).

Molecules

are typically structures with two or more atoms joined by bonds that can be covalent, or ionic.



COVALENT BOND
The bonding electrons are shared by both atoms.



IONIC BOND
An electron abandons the least electronegative atom to become part of the electron cloud of the more electronegative one.

Electricity

At present, the most used form of energy is electricity. This is because of the flexibility of the existing methods used in its generation, because of the advantages of using high-voltage power lines, and because electric engines are more efficient than heat engines. The drawbacks to this form of energy stem from the fact that it is not possible to store large amounts of electricity and the fact that transmission lines are expensive.

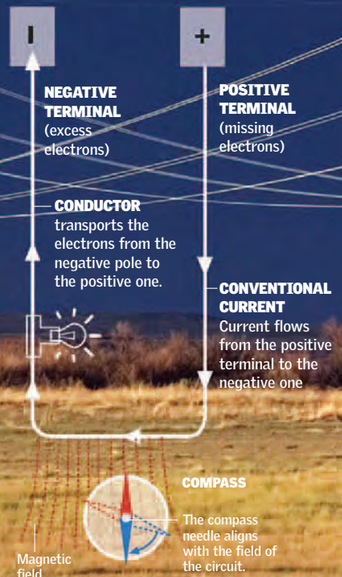
The World of Electrons

ELECTRIC CHARGE
An atom that loses or gains an electron is called an ion and becomes electrically charged.

POSITIVE ION
Atom lacking one or more electrons

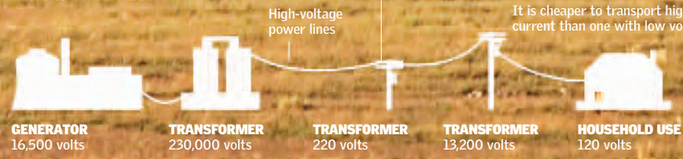
NEGATIVE ION
Atom with one or more extra electrons

CIRCUIT
By joining two objects of opposite charges with a conductor, an electrical circuit is formed.



MAGNETISM
A magnetic field, similar to that created by a magnet, is created around a wire with an electric current. The effects of this process can be seen on a compass.

DISTRIBUTION
To carry the current, the voltage needs to be increased.

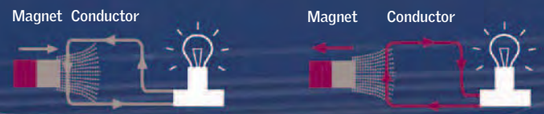


Industrial Production

The core of an electric power plant consists of the generators that use magnetism to produce electricity.

1 By moving a magnet across a conductor, a temporary current is produced.

2 If the magnet is moved away, the current flows in the opposite direction.



3 By keeping the magnet moving, the current remains constant but reverses direction continuously. This type of current is called alternating current (AC).

UNITS OF MEASUREMENT

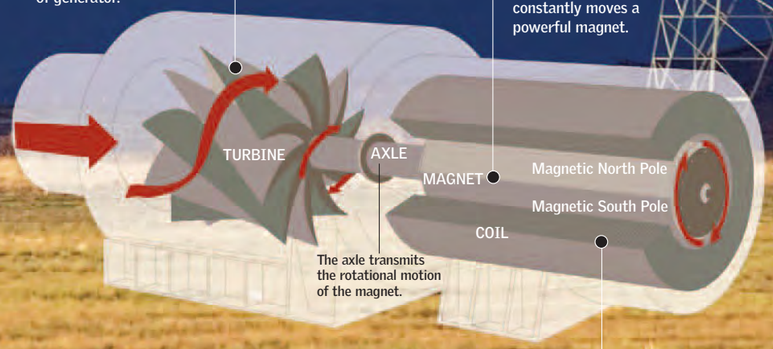
AMPERE	MAIN UNIT
VOLT	ELECTRIC POTENTIAL (VOLTAGE)
WATT	ELECTRIC POWER
OHM	ELECTRICAL RESISTANCE

How a Generator Works

1 **MOTIVE FORCE**
Water, steam, or wind is used depending on the type of generator.

2 **TURBINE**
Its blades convert the linear power into rotary power.

3 **ROTATING MAGNET**
The turbine constantly moves a powerful magnet.



TYPES OF GENERATORS	TURBINE MOVED BY
HYDROELECTRIC	WATER
WIND	WIND
THERMOELECTRIC	FUEL
THERMONUCLEAR	NUCLEAR POWER

4 **COIL**
A wound conductor that is connected to the circuit

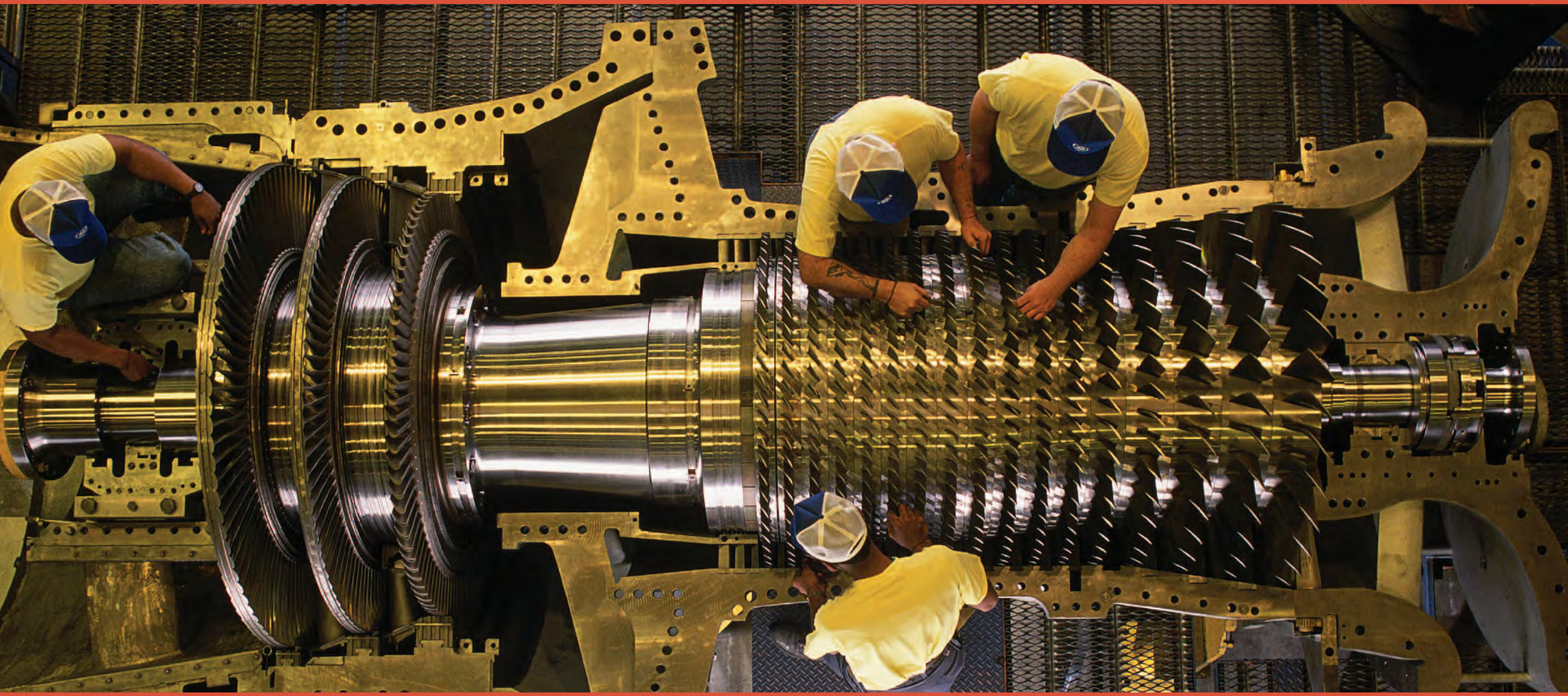
5 **ELECTRICITY**
The motion of the magnetic field on the coil generates an electric current.

60 CYCLES PER SECOND
Number of times that a full turn of the magnet is produced; the alternating current changes direction.

Manifestations of Energy

A TURBINE EVERY THREE DAYS
These workers are assembling a 38-megawatt gas turbine in a General Electric plant in South Carolina. On average, they assemble a turbine every three days.

THE WHEEL 18-19
THE PENDULUM 20-21
THE COMPASS 22-23
THE STEAM ENGINE 24-25
DYNAMITE 26-27
THE BATTERY 28-29
THE TURBINE 30-31



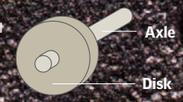
People have always looked for ways to harness energy. The first rudimentary tools were developed so that more work could be done with less effort. When humans abandoned tropical zones, they had to find ways of using energy to keep warm. From the development of fire-making techniques to the technology of modern nuclear reactors is but a small step if measured on a geologic scale. Here we present some of the machines and devices that people have invented and utilized over the course of history, from the simplest, such as the wheel or pendulum, to the most complex, such as the turbine and steam engine. ●

The Wheel

Together with fire, the wheel is one of the key inventions in the history of humankind. It was invented in Mesopotamia, where it was successful, and it was distributed through the Old World thanks to the abundance of large beasts of burden. Pre-Columbian American culture also discovered the wheel, but did not use it to go beyond the manufacture of toys and small artifacts; this scenario arose because of the lack of large beasts of burden to facilitate the use of vehicles—and also because the most advanced civilizations did not occupy flat terrain.

The wheel permits the movement of heavy objects with less effort than dragging them over a surface.

In its basic form, the wheel is a movable disk that rotates around a fixed axle.



DEVELOPMENT

Sleds
Previously the cargo was placed over two wooden guides that slid across the ground.

Rollers
The cargo was moved over a bed of wooden rollers. The rollers left free at the back were placed again in front.

Solid wheels
The first wheels were simple clay disks connected by a tree trunk.

Reducing Friction

The friction of the wheel with the axle makes the movement more difficult and causes the pieces to wear out quickly.

Leather bearing
Introduced by the Celts in France and Germany around 100 BC

Wooden rollers
A bed of small wooden bars that turn freely. This gave rise to modern bearings.

Wheels and Machines

The wheel transmits and transfers force.

Potter's wheel
The first use of the wheel, even earlier than its use in transportation

Mills
use the force of wind or water to grind grains or pump underground water to the surface.

Gears
permit the transmission and transformation of force into speed and vice versa.

Tripartite Wheel

The most common type of primitive wheel. It is still used in many parts of the world and is very suitable for rough terrain.

With spokes
Ideal for fabricating very light wheels

With rims
Combines lightness with toughness

Fenestrated
The first attempt to reduce the weight of the wheel

Tripartite
More versatile and economical than the solid wheel, it is also very resistant.

History

Solid wheel
A simple cross section of a tree trunk with a hole in its middle

STEEL RIMS
Their purpose is to reduce the wear of the wheel. They were used throughout the Middle Ages.

1 A red-hot iron hoop slightly larger than the wheel is placed over it.

2 After the metal cools, it contracts, strongly gripping the wood.

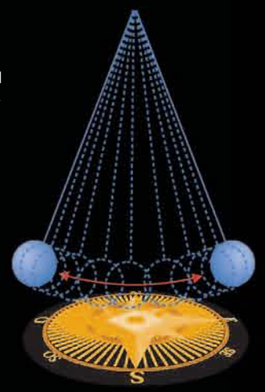
The Pendulum

This simple machine, whose physical principle was discovered by Galileo Galilei, has had many practical applications, especially in making clocks, in which the pendulum is used to drive the clock's inner workings. A small initial impulse can generate a considerable amount of motion that, through axles and gears, can be transformed into energy. The pendulum was used in 1851 by Jean-Bernard-Léon Foucault to demonstrate both the rotation of the Earth and the Coriolis effect.

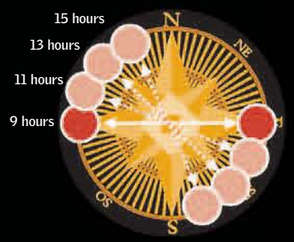
Foucault Pendulum

A device designed by the French physicist Jean-Bernard-Léon Foucault in 1851, which serves to demonstrate that the Earth revolves on its axis

THE EXPERIMENT
Foucault started the pendulum swinging and observed its oscillation.



The pendulum was sufficiently heavy to swing for several hours without stopping.



Little by little, the pendulum oscillated in a slightly different direction. After one day, it had made three fourths of a turn.

Foucault deduced that if the plane of oscillation of the pendulum cannot change, it was the Earth that revolved underneath the pendulum.

An imaginary pendulum on one of the two poles would always oscillate in the same direction.

Although, if seen from Earth, it would appear to rotate around its own axis.

The same is true if the pendulum is placed on a rotating plane, as in a carousel.

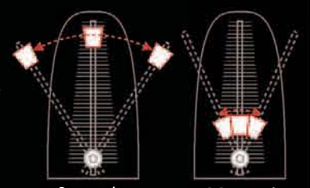
The pendulum always oscillates in the same direction, even if the carousel rotates.

To an observer on the carousel, the pendulum appears to turn.

Applications

METRONOME

It is used by musicians to measure time.
The duration depends on the distance between the weight and the point of rotation. The greater the distance, the longer the oscillation period.



CLOCK MAKING

The first mechanical clocks used pendulums to move their hands at a constant speed.
Each oscillation takes the same amount of time.

It has a symmetric weight that hangs from a string tied to a fixed point.

When the weight is moved from its equilibrium point, it oscillates.

Oscillation plane
The motion remains in a constant plane.

It stops because of air resistance and friction on the string.

High-tech Models

Pendulums are manufactured in large sizes, providing greater impulse and taking longer to slow down.

CONTINUOUS MOTION
Achieved using a ring-shaped electromagnet

When the string crosses a certain threshold, a sensor is activated that turns on the electromagnet. This process provides the necessary impulse to keep the pendulum from stopping.

The Compass

This invention uses the force of the Earth's magnetic field for its operation. The compass was of fundamental importance to navigation, because it allowed sailors to orient themselves on the open sea without having to observe the stars (which cannot be seen on cloudy nights or during the day). With the development of satellite-based global positioning systems, the use of compasses has greatly declined. However, because of their versatility, low weight, and low cost, compasses still have a place in some sporting and recreational activities.

Navigation Compass

The compass is used to trace a course on a navigation chart. Compasses range from simple handheld models, such as the one shown here, to complex models that were used for navigation at sea.

PIVOT
Low-friction support on which the needle sits

MAGNETIC NEEDLE
always orients itself with the Earth's magnetic north. By convention, the end that points north is colored red. More modern compasses replace the needle with a system of magnets.

BASELINE
is used to align the axis of the compass with the chosen direction.

POINTER
rotates with the graduated dial and points to the north on the dial.

GRADUATED DIAL
The rotating dial is graduated from 0 to 360º and includes the four cardinal points.

HOW TO FIND NORTH

The magnetized needle always points north.

The cardinal points are correctly positioned when the pointer lines up with the needle.

HOW TO FOLLOW A BEARING

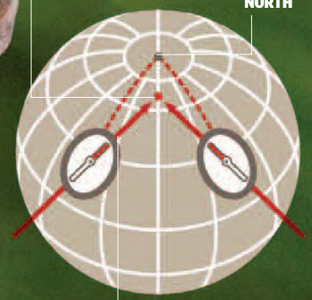
1 The compass is pointed toward the destination by aligning it with the baseline.

2 The graduated dial is rotated until the pointer is lined up with the magnetic needle.

3 Keeping the pointer lined up with the needle ensures that the direction is maintained.

MAGNETIC DECLINATION

MAGNETIC NORTH
does not coincide with the geographic north because the magnetic field varies with the movement of masses within the Earth.

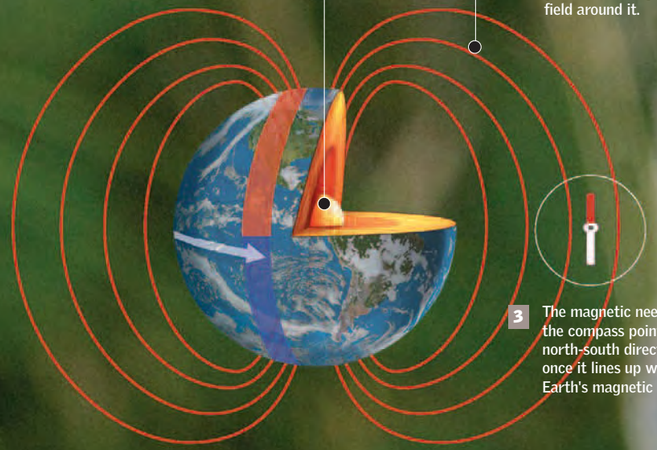


DECLINATION ANGLE
The angular difference between the magnetic and the geographic north. All navigation maps give this value to adjust for local compass readings.

THE EARTH'S MAGNETISM

1 The Earth has in its core a great mass of molten magnetic iron.

2 This turns it into a great magnet that generates a magnetic field around it.



3 The magnetic needle of the compass points in a north-south direction once it lines up with the Earth's magnetic field.

History

6th Century BC
Magnetite, a magnetic mineral, was discovered in Magnesia, Asia Minor.

1st Century AD
The Chinese already knew the usefulness of the magnet for navigating.

12th century
Arabs bring to Europe a compass similar to that used by the Chinese.

13th century
It is used for navigating the Mediterranean Sea.

15th century
Gimbals are used to keep a compass horizontal despite movements of the ship.

19th century
It is discovered that the magnetic north does coincide with the geographic one. Magnetic declination is studied.

20th century
More precise instruments and systems, such as radar, radionavigation, and satellite navigation, are implemented.

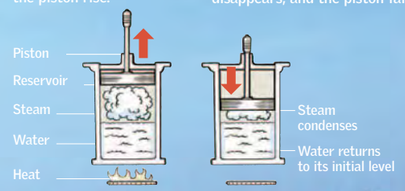
The Steam Engine

This external combustion engine, which transforms the energy in water vapor into mechanical work, was essential to the Industrial Revolution that took place in England in the 17th and 18th centuries. The history of its invention goes back to rudimentary devices without practical application and continues up to the invention of the steam engine by James Watt. The steam engine was of fundamental importance for industry and transportation, replacing beasts of burden, the mill, and even human laborers.

How It Worked

1 ASCENT
The pressure of the steam makes the piston rise.

2 DESCENT
Without heat, the steam condenses, the pressure disappears, and the piston falls.



COMPARISON OF SOURCES OF ENERGY ABOUT 1800

WATT'S STEAM ENGINE 11 TO 30 KILOWATTS = **14 TO 40** horses

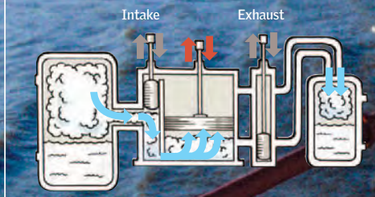
HORSE moving a mill **300 TO 450 WATTS** = **36.6 MEN** (minimum)

Watt's Innovation

added a separate container where the steam condenses.

1 The valves allow steam to pass through either from the top or from the bottom.

2 The piston goes up or down according to the intake of the steam.



3 The steam expelled by the motion of the piston becomes liquid in the condenser.

INNOVATOR	
NAME	JAMES WATT
NATIONALITY	SCOTTISH
OCCUPATION	ENGINEER

The changes he introduced made it possible to apply the steam engine to industrial processes.

Applications of the Era

Mainly in industry, mining, and transportation

WATER EXTRACTION
Basing his design on an earlier model, Thomas Savery in 1698 patented a steam engine that was used to extract water from mines. In 1712, Thomas Newcomen perfected it.

SPINNING AND WEAVING
It was used first to create spinning and weaving machines, and it was used later in printing presses.

STERILIZATION
About 1900, this model was built. It served, among other things, to sterilize water for nursing and for preparing medications.

TRANSPORTATION
In ships, cars, and locomotives. Some locomotives, like the Rocket, reached speeds close to 36 miles per hour (58 km/h).

GENERATING ELECTRICITY
Currently this is one of the steam engine's most important uses. The steam is sent through a turbine, and its mechanical energy is transformed into electrical energy.

Dynamite

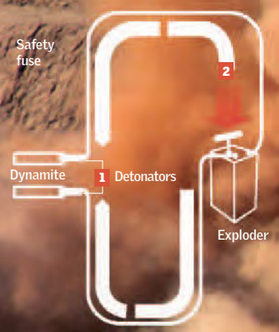
The term "dynamite" comes from the Greek word *dynamis*, which means "force." It was invented by Alfred Nobel in 1867, and it quickly replaced nitroglycerin, which was unstable and dangerous. Dynamite was the most commonly used explosive until 1950. It is so stable that new sticks in good condition generally do not explode even when exposed to fire; a detonator is necessary to make them explode. The fortune that Alfred Nobel earned with his invention was used for the creation of the award that carries his name.

How It Works

1 The detonators are connected to the sticks of dynamite. By means of a safety fuse, the detonators are attached to the central detonator.

2 When the detonator is activated, a small explosion is created, causing the subsequent explosion of the dynamite.

3 EXPLOSION
Dynamite explodes when the detonators are activated.



WHAT IT WAS USED FOR

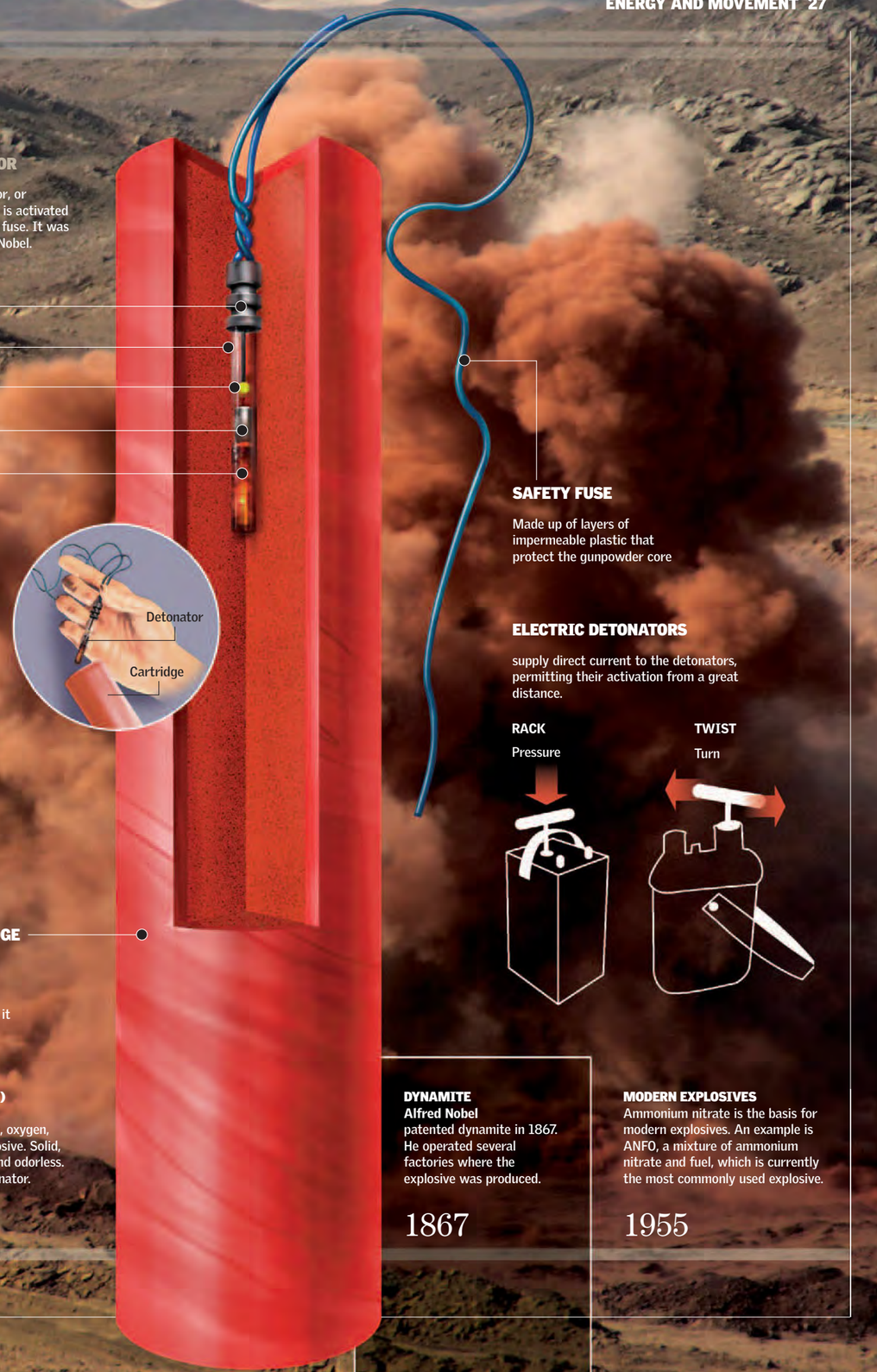
- Blasting in mines and quarries
- Tunnel construction
- Demolition
- Military use

What It Is Made of

3 PARTS NITROGLYCERIN
Glycerin + sulfuric acid + nitric acid
NITROGLYCERIN
Thick, oily, colorless or yellow liquid. Very volatile, sensitive to shock, friction, and heat.

+

1 PART DIATOMACEOUS EARTH (kieselguhr)
Very porous and absorbent material. When mixed with nitroglycerin, it produces a malleable paste, reducing nitroglycerin's notorious volatility.



History of Explosives

GUNPOWDER
Invented in China
Made of sulfur, carbon, and potassium nitrate. The first explosive in history, it was at first used only to shoot fireworks.
10th Century AD

NITROGLYCERIN
Ascanio Sobrero
Made with glycerol, sulfuric acid, and nitric acid. It is a very powerful explosive that is liquid and colorless. Unstable and very volatile, it explodes easily.
1846

NITROCELLULOSE
Christian Schönbein
Cellulose + nitric acid + sulfuric acid. It is known as smokeless gunpowder because it has great explosive power, but, unlike gunpowder, it does not give off black smoke.
1846

TNT (TRINITROTOLUENE)
Joseph Wilbrand
Made of carbon, hydrogen, oxygen, and nitrogen. Potent explosive. Solid, colorless or pale yellow, and odorless. It is exploded with a detonator.
1863

DYNAMITE
Alfred Nobel
patented dynamite in 1867. He operated several factories where the explosive was produced.
1867

MODERN EXPLOSIVES
Ammonium nitrate is the basis for modern explosives. An example is ANFO, a mixture of ammonium nitrate and fuel, which is currently the most commonly used explosive.
1955

The Battery

Generates electrical power by means of a chemical process that alters the characteristics of its components, and consequently a battery becomes discharged after a certain amount of use. The battery can produce an electric current between its two terminals, which are also known as poles or electrodes. The battery derives its name from the early practice of lining cells together horizontally, like batteries of troops.

Adding Together Energy

IN PARALLEL
The positive terminals are first connected to each other, followed by the negative ones.

The voltage remains the same, but the batteries last longer.

IN SERIES
The negative terminal of one connects to the negative terminal of the next one.

The voltage of the batteries is added. The power remains the same.

Two 1.5 V batteries produce 3 V.

9 V BATTERY

Formed by six 1.5 V cells in series.

1.5 V x 6 = 9 V

AA Model

Standard measurements (mm)

POSITIVE TERMINAL
has the shape of a circular button.

PLASTIC LINING
serves as insulation.

NICKEL-PLATED STEEL CASE
contains the active ingredients and is the positive collector.

CATHODE
Made of manganese dioxide and graphite, it receives electrons from an external circuit.

ELECTROLYTE
A solution of potassium hydroxide that transports the ionic current inside the cell

SEPARATOR
Made of porous, nonwoven fabric. It separates the electrodes and also contains the electrolyte.

ANODE
Zinc powder. It serves as the source of electrons.

ANODE COLLECTOR
Tin-covered metal. It conducts the electrons from the anode to the external circuit.

POSITIVE TERMINAL
receives the electrons from the circuit to keep the tension high.

OPERATION

NEGATIVE TERMINAL
produces the electrons that enter the circuit to make it work.

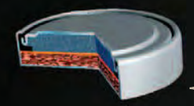
1. When the battery is connected to an electrical circuit, the **zinc** in the anode **oxidizes**.
2. For each zinc atom that oxidizes, two **electrons** are released.
3. A residue of very unstable **zinc ions** is left behind.
4. The anode collector conducts the electrons to the negative terminal of the cell.
5. From the **negative terminal,** the electrons enter the electrical circuit.
6. Takes up the electrons and transfers them to the cathode.
7. The electrons combine with the manganese dioxide to form negative ions.
8. These ions combine with the water in the electrolyte. They separate into negative hydroxide ions and positive hydrogen ions.
9. The negative hydroxide ions pass to the anode. They combine with the **unstable zinc ions,** generating zinc oxide and water.

When all the zinc has converted to oxide and water, the battery is discharged.

ALKALINE BATTERY

VOLTAGE	1.5 V
DURATION IN WATT-HOURS	2.5
IN AMPERE-HOURS	2.8

Types



1.5 V

CLOCK

Frequently made of lithium, it is more expensive but takes up less space than alkaline batteries.

1.2v

RECHARGEABLE

The most used are nickel metal hydride batteries. They have less voltage and a shorter life than alkaline batteries, but they can be recharged many times.

The Turbine

A turbine transforms the energy of fluids passing through it into the rotational motion of an axle. The fluid could be liquid, as in the hydraulic turbines of hydroelectric power plants, or gas, as in steam and gas turbines. The fluid pushes against blades mounted on components called a stator and a rotor. As the fluid pushes against the blades of the rotor, it produces rotational motion that causes the rotor to turn an axle.

The operating principle is the same one used in windmills.

PROPULSION/DIFFERENT APPLICATIONS

COMMERCIAL AIRPLANES use a turbofan system to save fuel.

WAR PLANES use a special type of turbine for greater thrust and speed.

HELICOPTERS use them to move their rotor blades, which support and propel them.

TANKS In tanks, like the M1, the turbines turn the wheels that move the treads.

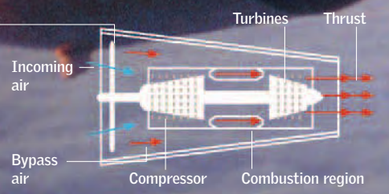
CARS Formula One cars use exhaust gases to produce additional power.

ENERGY Turbines are used in dams and rivers to utilize the force of water. They can also harness wind energy or be used in other electric-generation systems.

How Jet Propulsion Works

The turbine system has four phases: compression of incoming air, combustion, expansion, and exhaust of the gases. The result is thrust.

FRONT FAN sucks in great amounts of air, causing compression in the first stage, which eventually becomes thrust.

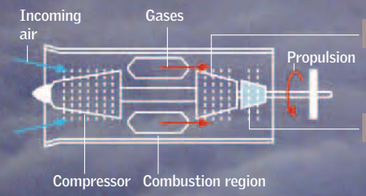


IN PASSENGER AIRPLANES

In large passenger jets, a front fan is added to the compressor. This system is called a turbofan engine.

IN HELICOPTERS, TANKS, AND SHIPS

the impulse of the gases is changed into rotational motion by means of a second turbine.

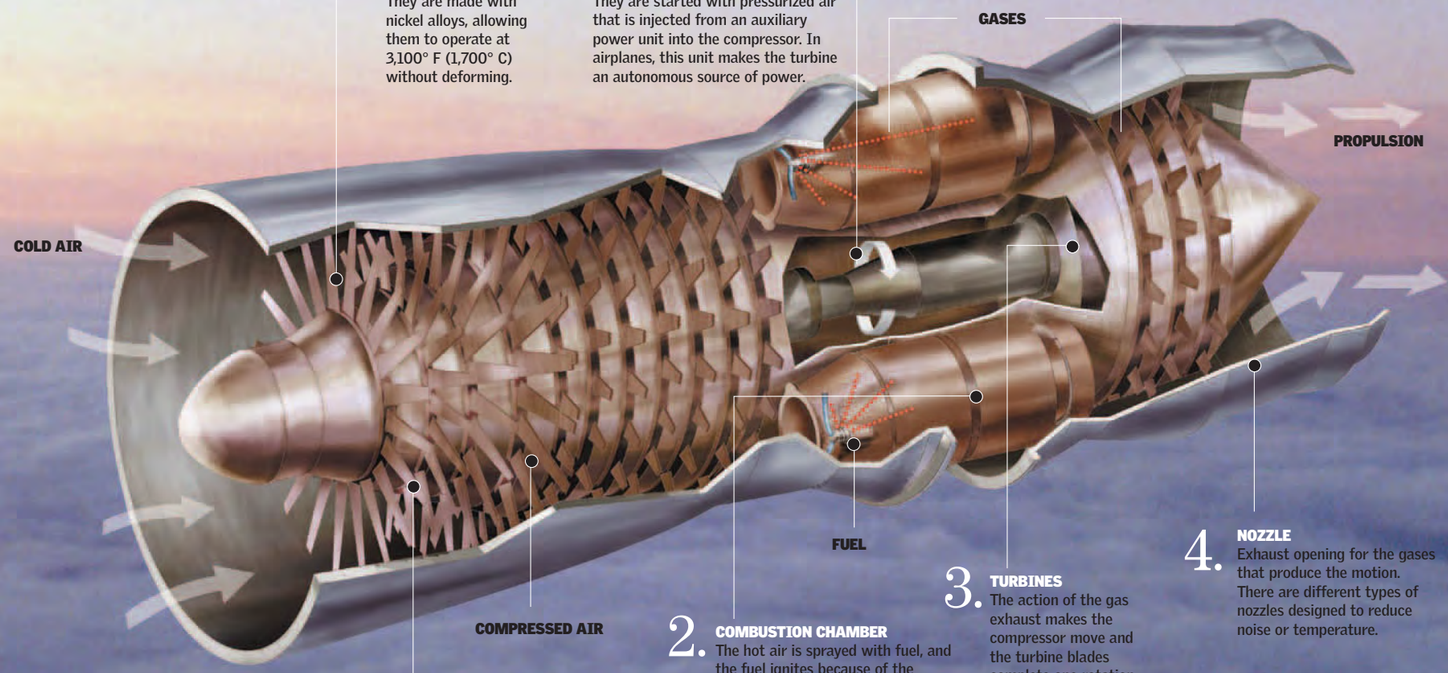


1 Turbine
The force of the gases makes the turbines rotate, thereby turning the compressor.

2 Gear box
Rotates independently and can move a motor, rotor blades (helicopters), or wheels and tracks (tanks).

MATERIAL
They are made with nickel alloys, allowing them to operate at 3,100° F (1,700° C) without deforming.

STARTUP
They are started with pressurized air that is injected from an auxiliary power unit into the compressor. In airplanes, this unit makes the turbine an autonomous source of power.



1. COMPRESSOR
The blades compress the incoming air, increasing its pressure and temperature and preparing it for combustion.

2. COMBUSTION CHAMBER
The hot air is sprayed with fuel, and the fuel ignites because of the elevated temperature inside the chamber. Gases are released at high speed and pressure.

3. TURBINES
The action of the gas exhaust makes the compressor move and the turbine blades complete one rotation.

4. NOZZLE
Exhaust opening for the gases that produce the motion. There are different types of nozzles designed to reduce noise or temperature.

Energy Resources

WIND ENERGY
Wind is one of the most promising renewable resources. Many countries take advantage of its force to generate electricity or pump water.

THE EARTH'S MAGNETISM 34-35
ULTRAVIOLET RADIATION 36-37
GRAVITY 38-39
NATURAL GAS 40-41
PETROLEUM 42-43
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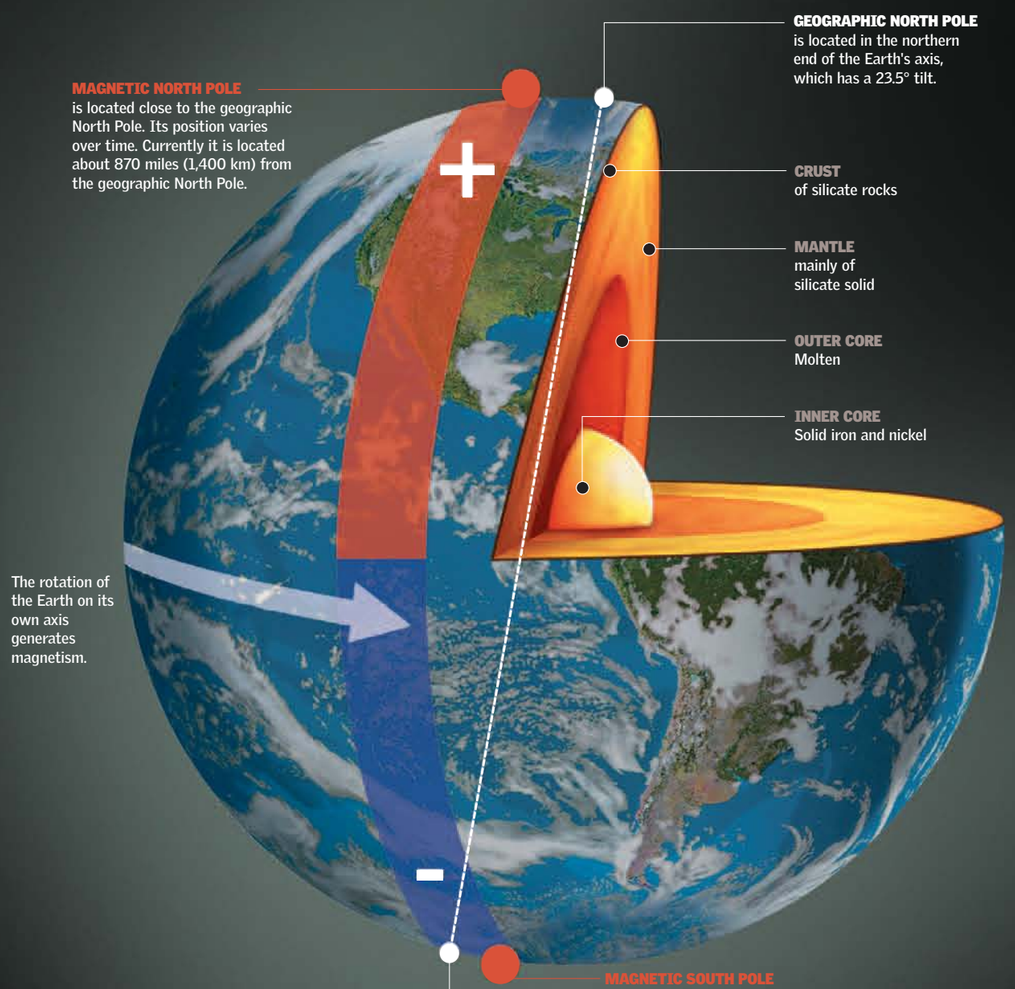
FISSION AND CHAIN REACTION 60-61

Nature is a giant power plant that generates clean, renewable energy. For this reason, faced with rapidly depleting petroleum, natural gas, and coal reserves, experts across the world have developed technologies to utilize alternative energies from the Sun, wind, water, and the interior of the Earth. Norway and Canada already obtain much of their electricity from hydroelectric power plants. Some architectural designs also seek to take maximum advantage of solar energy to heat homes, offices, and greenhouses.

In some places in the United States and various European countries, wind farms are used to produce electricity. ●

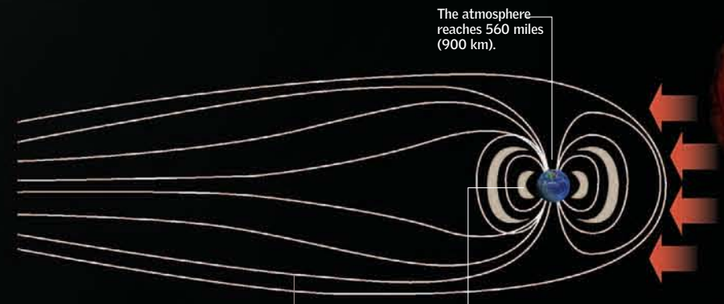
The Earth's Magnetism

The Earth behaves like a giant bar magnet and has a magnetic field with two poles. It is likely that the Earth's magnetism results from the motion of the iron and nickel in its electroconductive core. Another probable origin of the Earth's magnetism lies in the convection currents caused by the heat of the core. The Earth's magnetic field has varied over the course of time. During the last five million years, more than 20 reversals have taken place. The most recent one occurred 700,000 years ago. The interaction of the Earth's magnetic field with the Sun's magnetic field produces phenomena such as the aurora borealis and australis; the interaction can also cause interference in radio-wave transmissions.



MAGNETOSPHERE

The invisible lines of force that form around the Earth. It has an ovoid shape and extends 37,000 miles (60,000 km) from the Earth. Among other things, it protects the Earth from harmful particles radiated by the Sun.



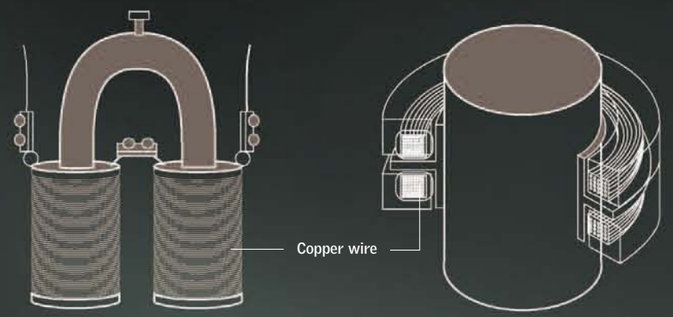
PLANETARY AND SOLAR MAGNETISM

The planets in the solar system have various magnetic fields with varying characteristics.

The four giant planets possess stronger magnetic fields than the Earth.

SUPERCONDUCTOR MAGNETS

generate magnetic fields, as the Earth does. They are stronger than ordinary electromagnets and can generate more energy. They have many uses, from railway transportation to nuclear medicine.



Ultraviolet Radiation

Invisible to the human eye (but not to many birds, reptiles, and insects), the short wavelengths of this electromagnetic radiation are harmful to living beings. Fortunately the ozone layer in the atmosphere filters out almost all the dangerous radiation but lets through beneficial rays. UV rays are used in astronomy, mineralogy, plague control, spectrophotometry, and the sterilization of surgical material.

Incidence on the Earth

CLOUDS
The clouds reduce ultraviolet radiation by an average of 20 percent.

ALTITUDE
The intensity increases by 4 percent with every 1,000 feet (300 m) of altitude.

+8% 600 m
+4% 300 m
0 m

-20%
SNOW
+80%

SAND
+25%

WATER
+10%

GRASS
+15%

REFLECTION
The direct intensity of the radiation increases with reflected radiation.

IN THE LIGHT SPECTRUM

SOLAR SPECTRUM
X-RAYS
VISIBLE LIGHT
UV RAYS
INFRARED RADIATION

Meters

10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{0} 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14}

RADIO WAVES | TV WAVES | MICROWAVES | INFRA-RED RAYS | VISIBLE LIGHT | UV RAYS | X-RAYS | GAMMA RAYS

CLASSIFICATION

100 | 280 | 315 | 400

UVA
Tans without reddening the skin; has a cumulative effect

Reach the Earth's surface

UVB
More intense and more harmful for the biosphere than UVA radiation

90 percent is blocked by the ozone and oxygen in the atmosphere.

UVC
Incompatible with animal and plant life

The ozone layer completely blocks them.

Wavelength in nanometers (10^{-9} m)

OZONE LAYER

The ozone layer is located in the stratosphere (10 to 15 miles [15 to 25 km] high) and protects the Earth by absorbing UV rays.

Thickness of the layer. The thinner it is, the less radiation it filters.

NATURAL THINNING
The ozone layer gets thinner in spring because of magnetic storms in the upper atmosphere and because of photochemical reactions.

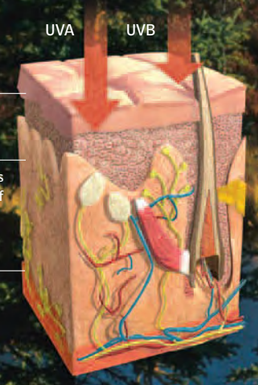
SEASONS
In spring and summer, the intensity of the solar radiation increases.

LATITUDE
The intensity is greatest at the Equator and decreases toward the poles.

HOURS OF THE DAY
Greatest intensity between **10 A.M. AND 4 P.M.**

Effects on Humans

THE SKIN
UV rays can cause sunburn, an inflammation of the skin. Melanin, a dark pigment, helps protect the skin from UV rays. Over time, prolonged exposure to the UV rays in sunlight harms skin fibers and can lead to wrinkling, dryness, and skin cancer.



IMMUNE SYSTEM
Its weakening increases the likelihood of contracting infectious diseases.

EYES
Cataracts and other eyesight disorders

Animals

Like humans, animals can suffer from skin cancer, weakening of the immune system, and eye injury.

Vegetables

Soy and rice plants exposed to UVB rays are smaller and have lower yield.

Phytoplankton

THE FIRST LINK IN THE FOOD CHAIN. ITS LOSS IS CAUSED IN PART BY INCREASES IN UV RADIATION.

Gravity

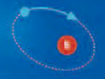
This is the name given to the mutual attraction of two objects with mass. It is one of the four fundamental forces observed in nature. The effect of gravity on a body tends to be associated, in common language, with the concept of weight. Gravity is responsible for large-scale movements throughout the universe; it causes, for example, the planets in the solar system to orbit the Sun. In astronautics, the energy of gravitational fields is used to accelerate or slow down space probes, changing their trajectories and allowing them to move toward new, less accessible destinations.

How Gravity Works

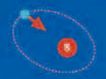
The force that keeps the stars together in the galaxies and our feet firm on the ground

IN SPACE

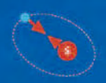
FIRST LAW
A planet does not move in a straight line, because there is a force (from the Sun) that gravitationally attracts it.



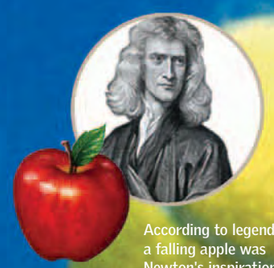
SECOND LAW
The acceleration that this force produces is such that the planet's orbital path is an ellipse that has the Sun as one of its foci.



THIRD LAW
If the Sun exerts a force on the planet, the planet exerts a force on the Sun with the same intensity but in the opposite direction.



Gravity is a property of all bodies with mass (people, things, planets, stars, and so on).



1642-1727

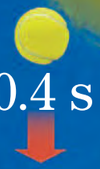
ISAAC NEWTON
conceptually unified the dynamics of stars with the Earth's gravitation and untangled the secrets of light and color.

According to legend, a falling apple was Newton's inspiration.

LAW OF UNIVERSAL GRAVITATION
is the attractive gravitational force between two masses in the universe.

DIRECTLY PROPORTIONAL TO THE PRODUCT OF THEIR MASSES

Since the Earth's mass is greater, the force of gravity is more intense.



0.4 s

ON EARTH

How long a ball takes to fall 3 feet (1 m) on the Moon

1.1 s

ON THE MOON

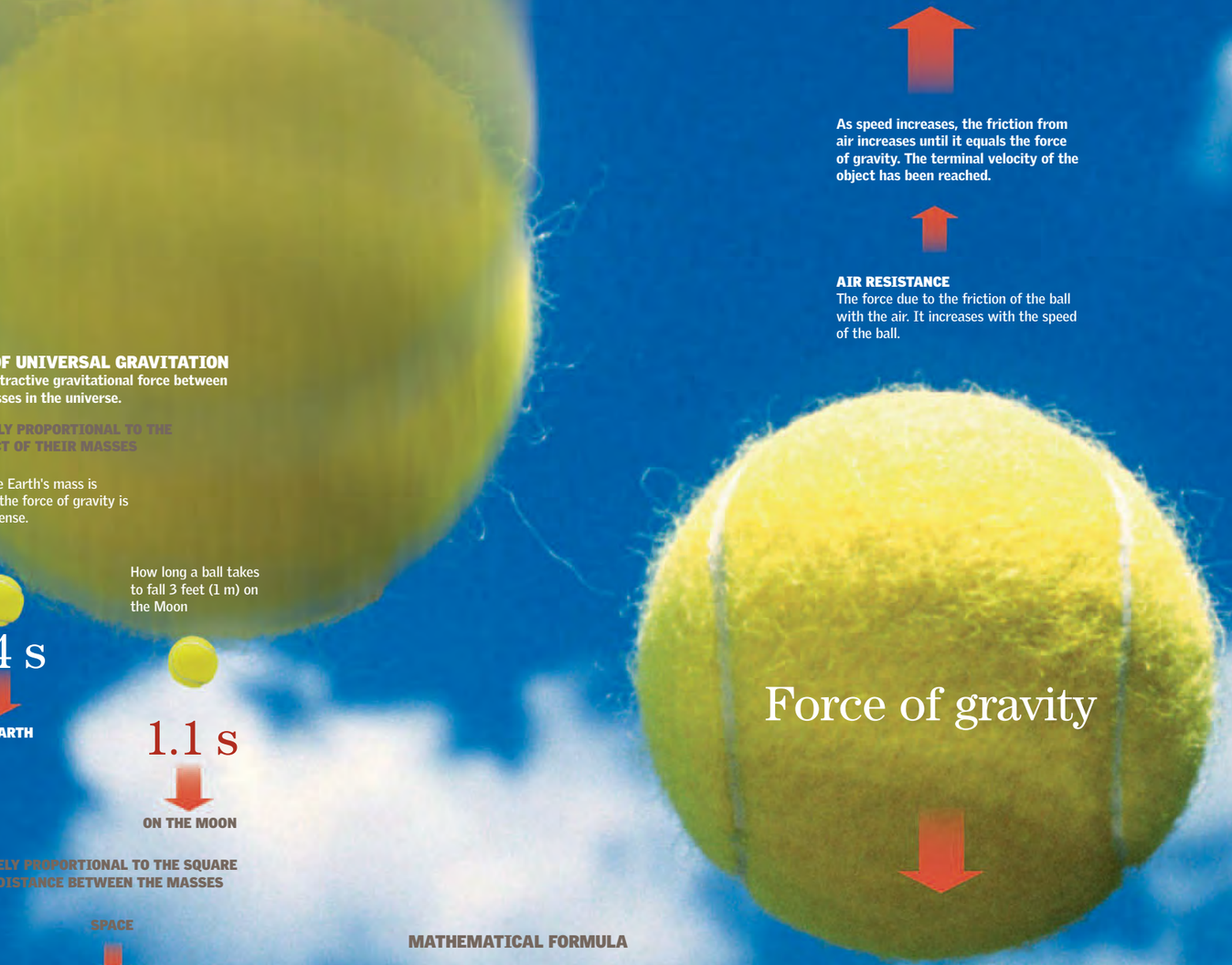
INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE BETWEEN THE MASSES

SPACE

As we move away from the Earth's center, the force of gravity decreases.

In space, the weight of a ball decreases because the force of gravity is less, even though its mass does not change.

EARTH



As speed increases, the friction from air increases until it equals the force of gravity. The terminal velocity of the object has been reached.

AIR RESISTANCE
The force due to the friction of the ball with the air. It increases with the speed of the ball.

Force of gravity

MATHEMATICAL FORMULA

$$F = G \frac{Mm}{d^2}$$

$6.673 \times 10^{-11}\ m^3/(kg\ s^2)$

is the constant of universal gravitation.

Gravity always acts downward toward the Earth's center.

Natural Gas

After petroleum, natural gas slowly rose to a position of importance in the global balance of energy sources because of its availability and efficiency. It has a reputation of being the cleanest fossil fuel. Technological advances, especially in the discovery of deposits, have produced an explosion in the reserve statistics in the last 15 years. These developments have been accompanied by an ever-increasing dependency on natural gas in different parts of the planet.

Phantom Energy

Natural gas is a colorless, odorless fluid that contains between 70 and 90 percent methane, the component that makes it useful as a source of energy.

2 REFINEMENT
The solid and wet components are separated. Then the byproducts, like propane and ethylene, are separated.

1 EXTRACTION
The gas is extracted from the deposit through a hole. When the gas is under pressure, it rises to the surface on its own. When it is not under pressure, it must be pumped.

3 DISTRIBUTION
After being distilled and converted essentially into methane, natural gas is distributed for use through gas pipelines.

4 LIQUEFACTION
When it must be transported by sea or stored, the gas is compressed and cooled to -258° F (-161° C) to liquefy it.

Lossless Trip

Among the many virtues of natural gas is the efficiency with which it can be transported. From gas deposits, it can be sent thousands of miles by ship or through gas pipelines with minimal losses.

5 TRANSPORT
Large, double-hulled, pressurized ships transport the gas in a liquid state.

6 GASIFICATION
After transport, the liquefied gas is returned to the gaseous state to be distributed through a network of gas mains.

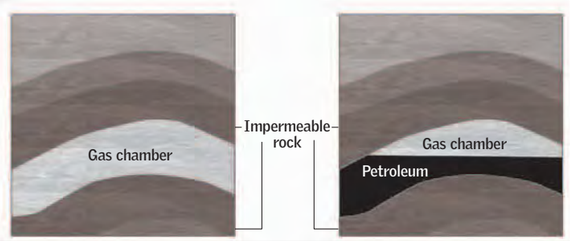
7 DISTRIBUTION
The gas reaches residential and commercial consumers.

1/600
The reduction in volume of natural gas when it is liquefied for storage or transport

LPG

Liquefied petroleum gas (LPG) is a byproduct of natural gas. It is bottled in cylinders and used by people who live in remote areas to operate, for instance, boilers and motors.

Deposit
Gas tends to be located inside porous rocks capped by impermeable rocks that are not necessarily associated with petroleum.



Reserves

The largest reserves of natural gas in the world are found in Russia and the Middle East.

Country	Trillion cubic feet	% of Total
Russia	1,680	27.4
Iran	971	15.9
Qatar	911	14.9
Saudi Arabia	241	3.9
United Arab Emirates	214	3.5
United States	204	3.3
Nigeria	185	3.0
Algeria	161	2.6
Venezuela	151	2.5
Iraq	112	1.8
Indonesia	98	1.6
Norway	84	1.4
Malaysia	75	1.2
Rest of the world	1,037	16.9

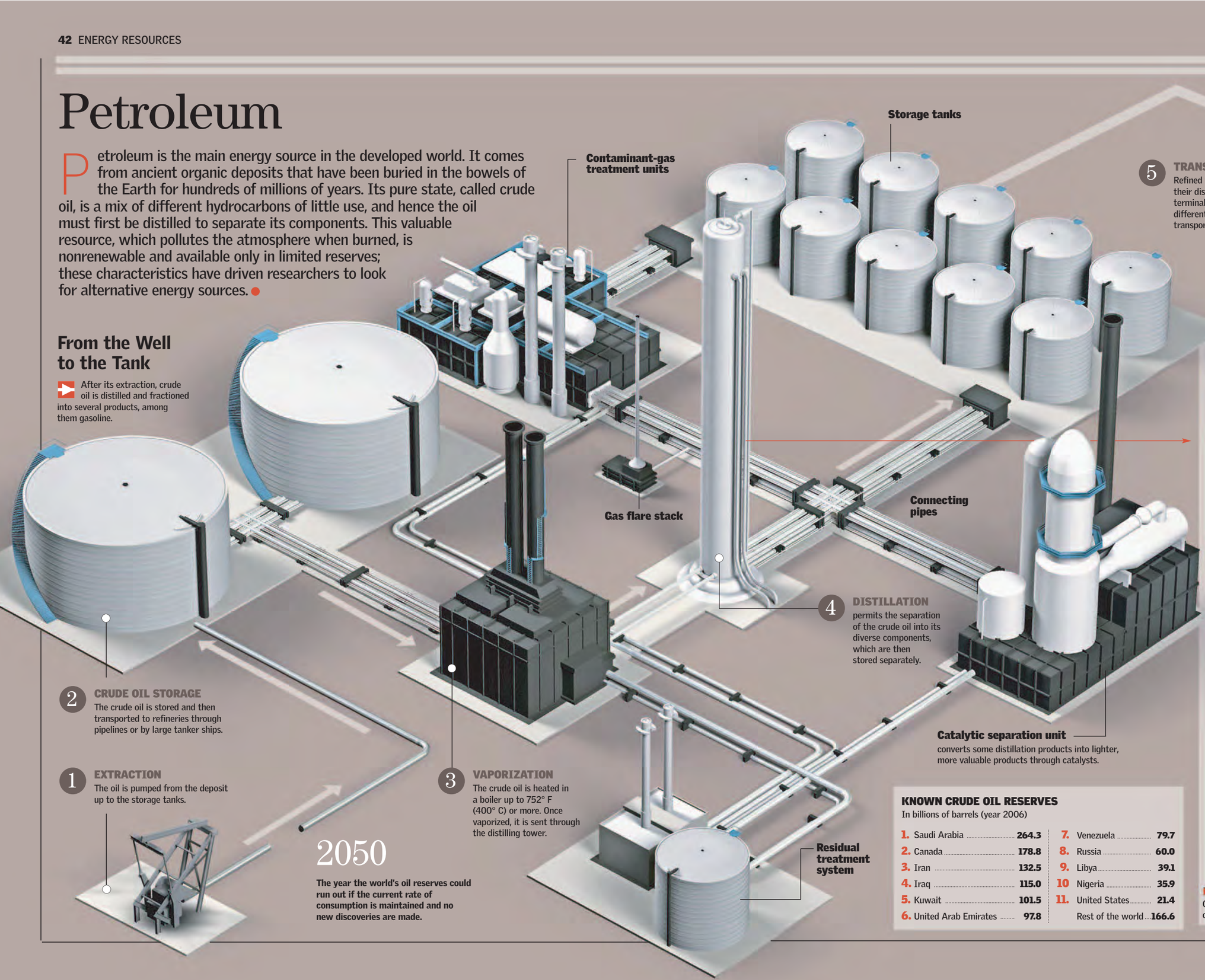
6,124
trillion cubic feet is the total of the known reserves in the world.

Petroleum

Petroleum is the main energy source in the developed world. It comes from ancient organic deposits that have been buried in the bowels of the Earth for hundreds of millions of years. Its pure state, called crude oil, is a mix of different hydrocarbons of little use, and hence the oil must first be distilled to separate its components. This valuable resource, which pollutes the atmosphere when burned, is nonrenewable and available only in limited reserves; these characteristics have driven researchers to look for alternative energy sources.

From the Well to the Tank

After its extraction, crude oil is distilled and fractioned into several products, among them gasoline.



2 CRUDE OIL STORAGE
The crude oil is stored and then transported to refineries through pipelines or by large tanker ships.

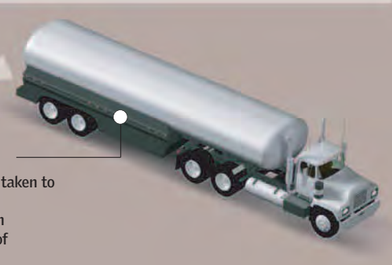
1 EXTRACTION
The oil is pumped from the deposit up to the storage tanks.

3 VAPORIZATION
The crude oil is heated in a boiler up to 752° F (400° C) or more. Once vaporized, it is sent through the distilling tower.

4 DISTILLATION
permits the separation of the crude oil into its diverse components, which are then stored separately.

Catalytic separation unit
converts some distillation products into lighter, more valuable products through catalysts.

5 TRANSPORT
Refined fuels are taken to their distribution terminals through different means of transport.



49 gallons (159 l)

The measure of a barrel of petroleum. Currently the global demand for petroleum is about 86 million barrels per day.

2050

The year the world's oil reserves could run out if the current rate of consumption is maintained and no new discoveries are made.

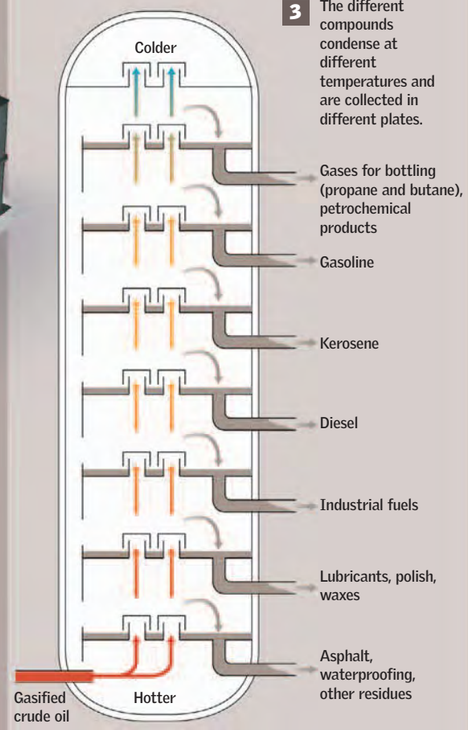
Distillation

The process through which oil is refined. It consists of applying heat to crude oil to separate its components, which all have different boiling and condensation points.

1 After being heated to 752° F (400° C), the oil enters as vapor into the lower reaches of the distillation tower.

2 The vapor rises, crossing a series of perforated plates. As it rises, it cools.

3 The different compounds condense at different temperatures and are collected in different plates.



KNOWN CRUDE OIL RESERVES

In billions of barrels (year 2006)

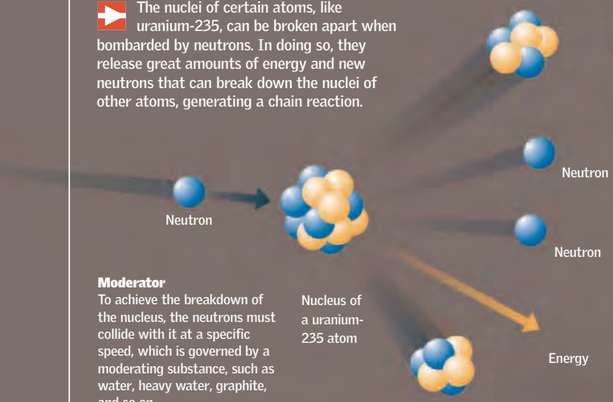
1.	Saudi Arabia	264.3	7.	Venezuela	79.7
2.	Canada	178.8	8.	Russia	60.0
3.	Iran	132.5	9.	Libya	39.1
4.	Iraq	115.0	10	Nigeria	35.9
5.	Kuwait	101.5	11.	United States	21.4
6.	United Arab Emirates	97.8		Rest of the world	166.6

Nuclear Energy

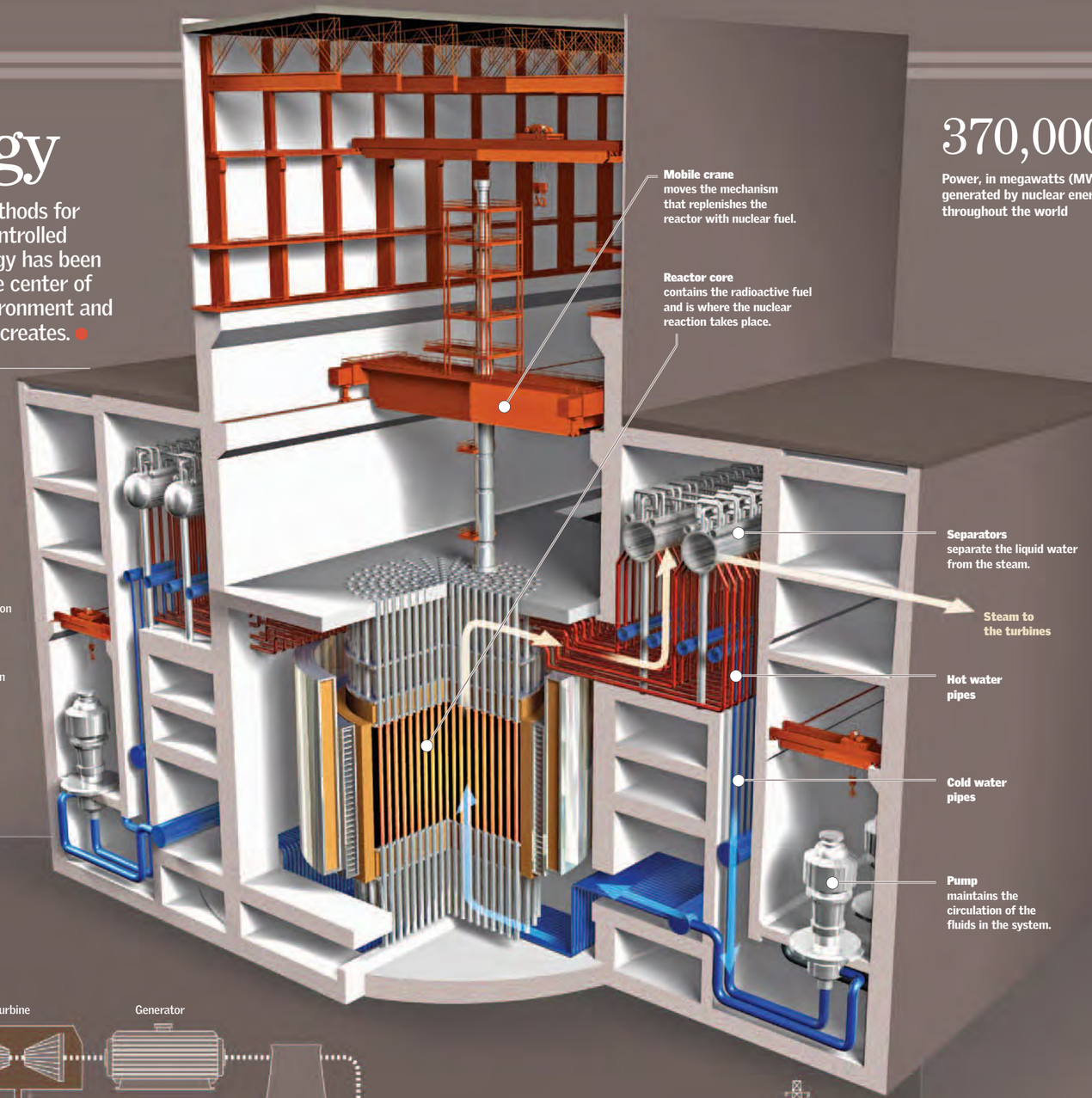
One of the most efficient and cleanest methods for obtaining electric energy is through a controlled nuclear reaction. Although this technology has been used for half a century, it continues to be at the center of debate because of the risks it poses to the environment and health and because of the highly toxic waste it creates.

Fission

The nuclei of certain atoms, like uranium-235, can be broken apart when bombarded by neutrons. In doing so, they release great amounts of energy and new neutrons that can break down the nuclei of other atoms, generating a chain reaction.

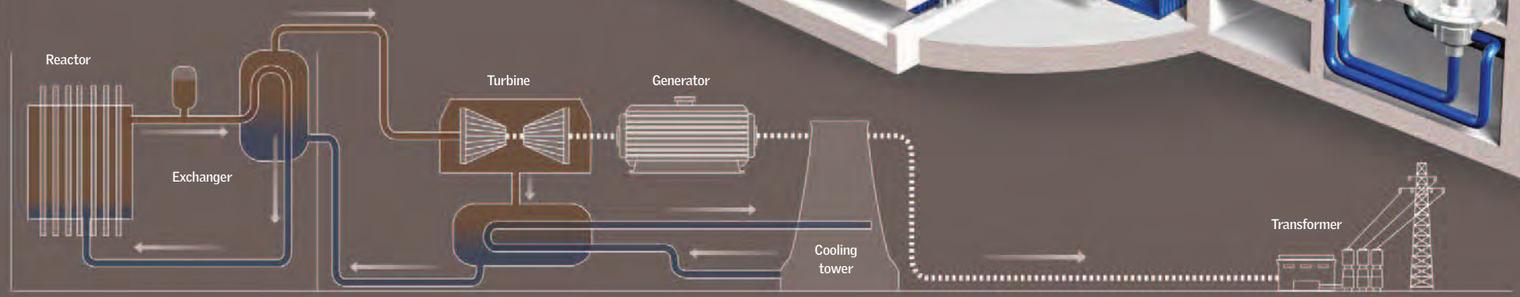


Moderator
To achieve the breakdown of the nucleus, the neutrons must collide with it at a specific speed, which is governed by a moderating substance, such as water, heavy water, graphite, and so on.



Generation of Energy

The purpose of nuclear fission is to create very hot steam to operate turbines and electrical generators. The high temperatures are achieved by using nuclear energy from the reactor.



1. **Water**
Pressurized water, together with the moderator, is pumped through the core of the reactor, and the temperature of the core increases by hundreds of degrees.

2. **Steam**
The resulting steam enters an exchanger, where it heats water until it too is converted into steam.

3. **Electricity**
The steam enters the turbines and makes them run. The turbines drive the generator that produces electricity.

4. **Recycling**
The steam condenses into liquid water and is reused.

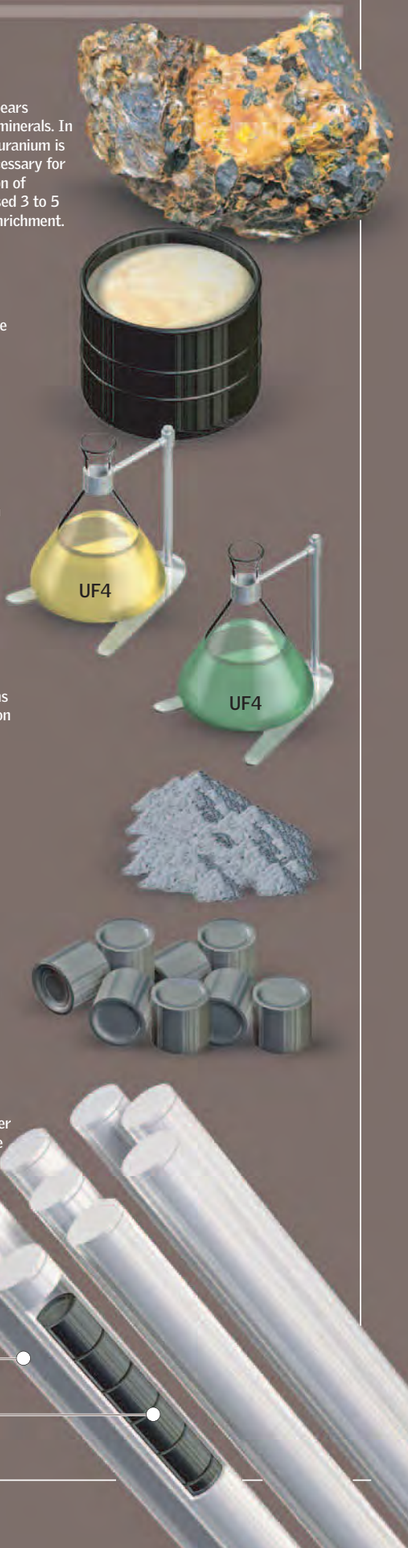
5. **Transport**
Before transmitting electricity, a transformer increases its voltage.

370,000
Power, in megawatts (MW), generated by nuclear energy throughout the world

436
The number of nuclear plants operating throughout the world. More than 30 are in various stages of construction.

Uranium

In nature, uranium appears associated with other minerals. In addition, only 0.7 percent of uranium is the isotope uranium-235, necessary for nuclear fission. The proportion of uranium-235 must be increased 3 to 5 percent in a process called enrichment.



1. The original mineral is treated until a substance called yellowcake is obtained that is 80 percent uranium.

2. During conversion, first uranium tetrafluoride (UF4) and then uranium hexafluoride (UF6) are obtained.

3. The gaseous uranium hexafluoride is spun repeatedly in a centrifuge until it attains the desired concentration of uranium-235.

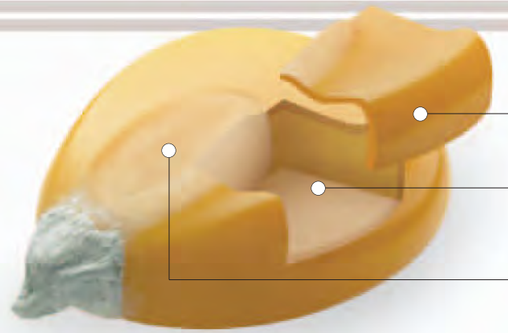
4. The enriched uranium gas is solidified again.

5. Through compaction, pellets of enriched uranium are obtained that can be used as fuel in nuclear reactors.

6. The pellets are put into hollow bars that are later placed in the core of the nuclear reactor.

Biofuels

Gasoline or diesel with added alcohol (ethanol) produced from crops such as corn appear more and more promising as solutions to the problems posed by the eventual exhaustion of the Earth's petroleum reserves, as well as the high cost of fossil fuels on the global market. However, this type of energy presents new challenges. One item of environmental concern is the possibility that massive exploitation of biofuels could lead to the replacement of jungles and woodlands with single-crop plantations meant only for the production of raw plant materials.



KERNEL OF CORN

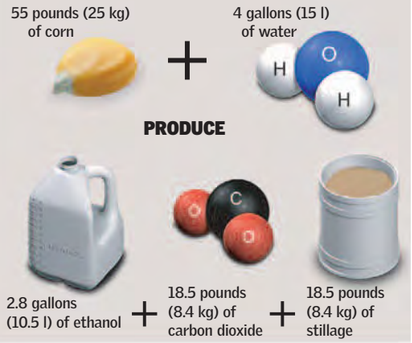
HULL
protects the seed from water, insects, and microorganisms.

ENDOSPERM
represents 70 percent of the weight of the dry grain. It contains starch, the substance used to produce ethanol.

GERM
The most valuable and the only living part of the grain. In addition to containing the genetic material, vitamins, and minerals, it is 25 percent oil.

Byproducts

are generated during the production of ethanol. Anhydrous carbon is used in the manufacture of soft drinks. The stillage, a very nutritious residue, is used to feed cattle.



Ethanol

This is the alcohol in the medicine cabinets of our homes. It can be used in its pure form as a fuel or combined with gasoline in different proportions. The greater its purity, the greater are the engine modifications required to burn the fuel. Two common mixtures are E10 and E85, which have 10 percent and 85 percent ethanol, respectively.

1 HARVEST
Sugarcane, beets, corn, yucca, potatoes, and even wood can be used, with varying degrees of efficiency, to produce ethanol.

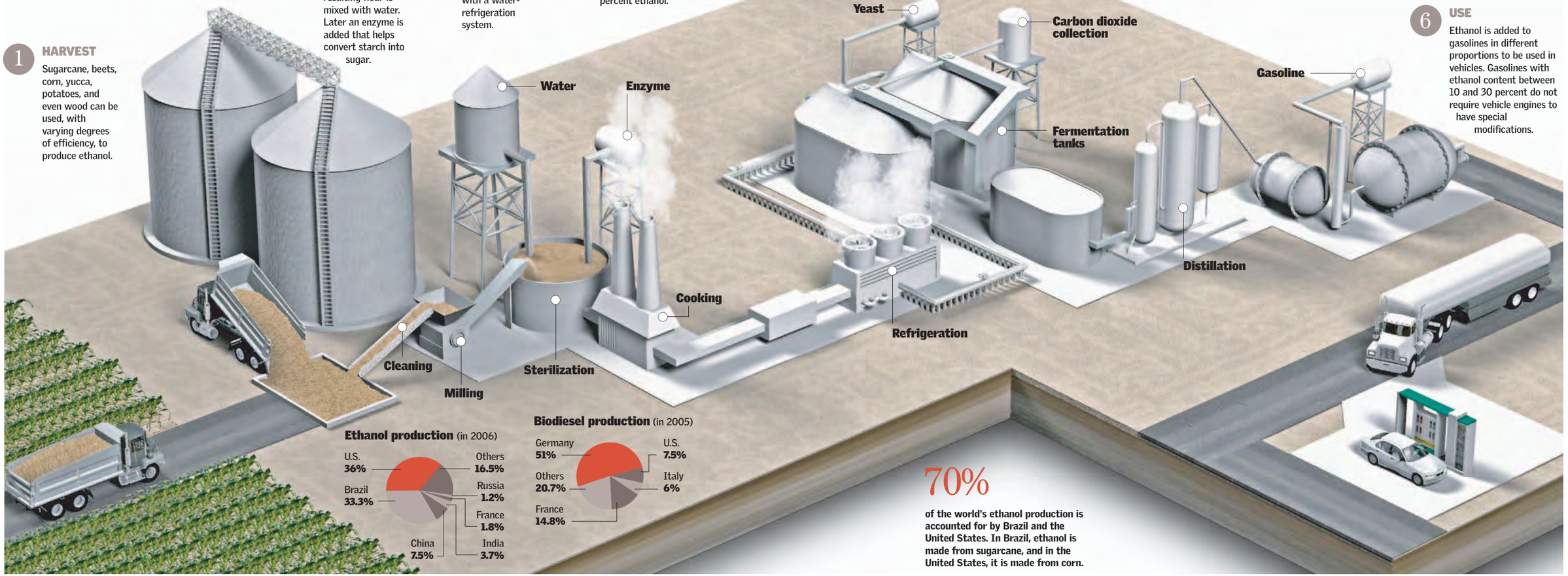
2 MILLING
The raw material is milled, and the resulting flour is mixed with water. Later an enzyme is added that helps convert starch into sugar.

3 COOKING
The mixture is cooked at 300° F (150° C) (sterilization) and is finally cooled with a water-refrigeration system.

4 FERMENTATION
Yeast is added to convert sugar into ethanol. This process, which produces heat and carbon dioxide, lasts 60 hours. When finished, the mixture, called mash, is 15 percent ethanol.

5 DISTILLATION
The mixture is distilled first by evaporation to obtain 96 percent pure ethanol. It is later distilled by a molecular filtration process that can produce ethanol that is almost entirely pure. A 5 percent gasoline mixture is used for transportation.

6 USE
Ethanol is added to gasolines in different proportions to be used in vehicles. Gasolines with ethanol content between 10 and 30 percent do not require vehicle engines to have special modifications.



Ethanol production (in 2006)

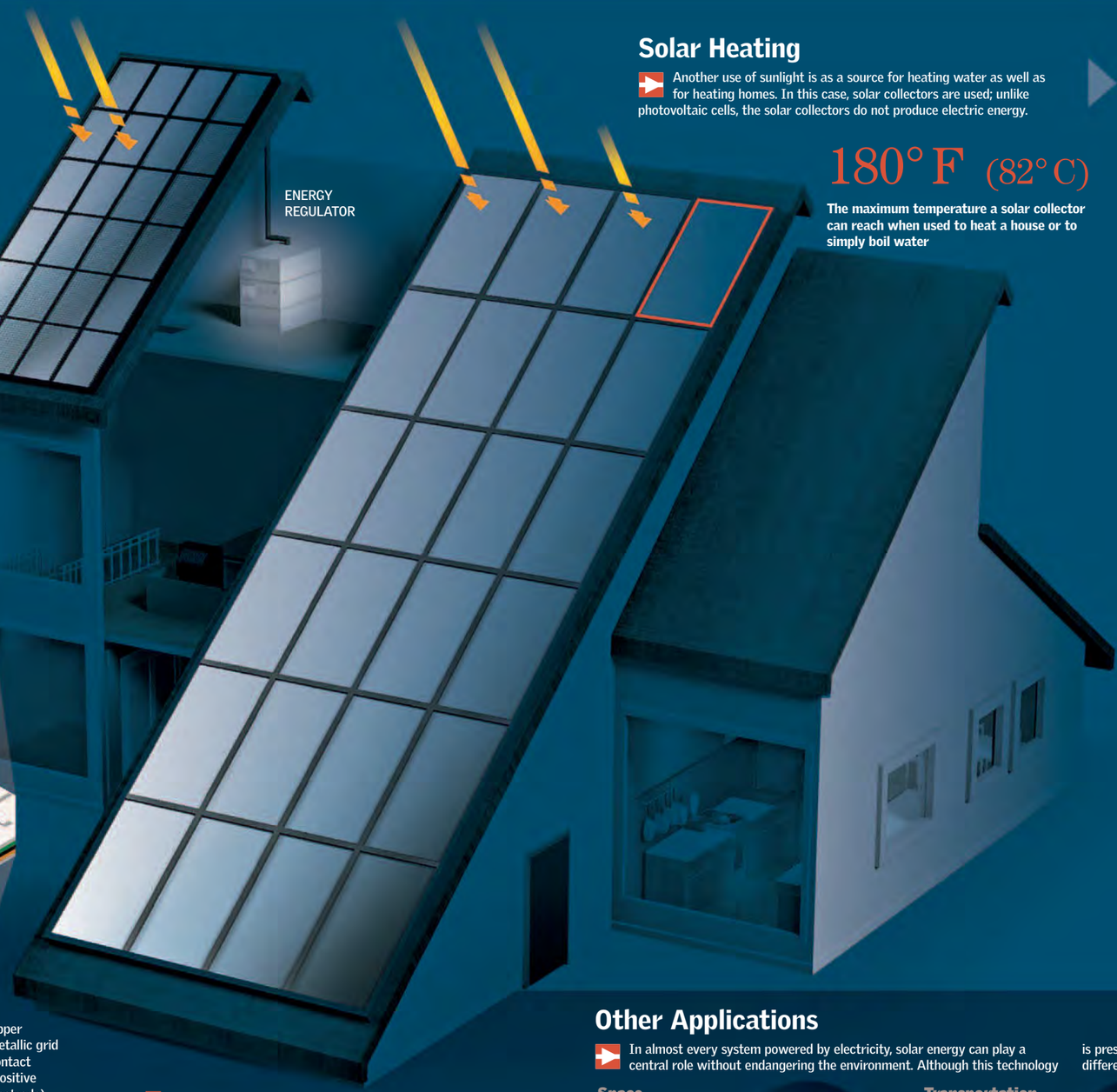
Biodiesel production (in 2005)

70%

of the world's ethanol production is accounted for by Brazil and the United States. In Brazil, ethanol is made from sugarcane, and in the United States, it is made from corn.

Solar Energy

The harnessing of solar energy to produce electricity and heat for everyday use is gaining popularity. Applications of this clean, unlimited form of energy range from charging batteries in telecommunications satellites, to public transportation, all the way to the solar households being built in greater numbers throughout the world.



Photovoltaic Energy

The energy obtained from sunlight. Requires the use of solar or photovoltaic cells.

SOLAR CELL

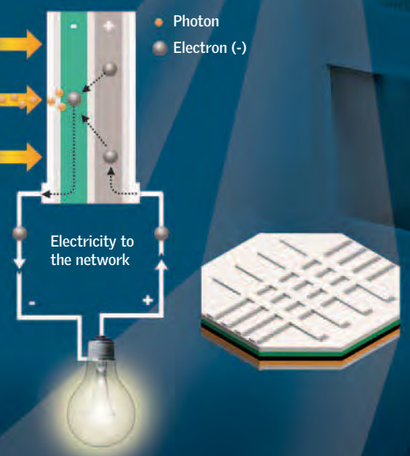
It is essentially formed by a thin layer of semiconductor material (silicon, for example), where the photovoltaic effect—the transformation of light into electrical energy—takes place.

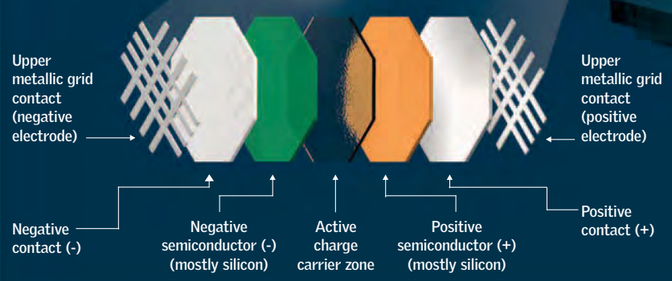
1 The Sun shines on the cell. Some very energetic photons move the electrons and make them jump to the illuminated face of the cell.

2 The negatively charged electrons generate a negative terminal on the illuminated face and leave an empty space in the positively charged dark face (positive terminal).

3 Once the circuit is closed, there is a constant flow of electrons (electric current) from the negative terminal to the positive one.

4 The current is maintained as long as the Sun illuminates the cell.





Solar Heating

Another use of sunlight is as a source for heating water as well as for heating homes. In this case, solar collectors are used; unlike photovoltaic cells, the solar collectors do not produce electric energy.

180° F (82° C)

The maximum temperature a solar collector can reach when used to heat a house or to simply boil water

THE COLLECTOR

works using the greenhouse effect. It absorbs the heat from the Sun and then prevents this heat from being lost. In doing so, it warms a pipe, through which the fluid (water or gas) flows, that in turn heats a tank (exchanger).

Protective Cover

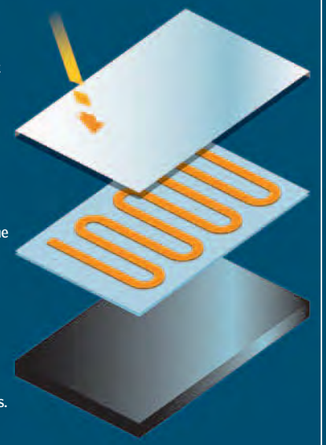
is formed by one or several glass plates. It lets sunlight through but retains the heat accumulated in the collector.

Absorption Plate

contains tubing, generally made of copper, through which the fluid heated in the collector flows.

Thermal Plate

The reflecting material and the black color absorb as much of the Sun's heat as possible. The protective plate then prevents any loss.



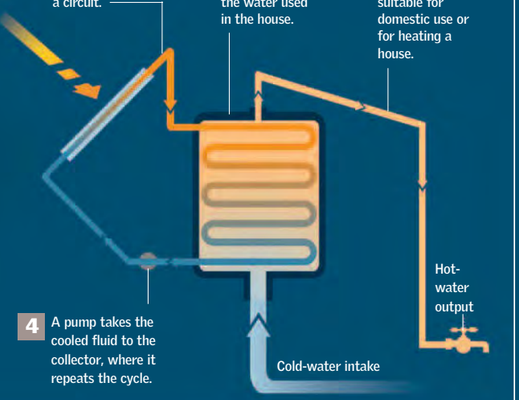
HOT WATER AND HEATING CIRCUIT

1 The hot liquid flows from the collector through a circuit.

2 It enters a heat exchanger, where it heats the water used in the house.

3 The water leaves the exchanger at a temperature suitable for domestic use or for heating a house.

4 A pump takes the cooled fluid to the collector, where it repeats the cycle.



Investment

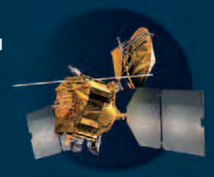
One of the main problems with using solar energy on an industrial scale is the high startup cost required to harness the energy; this cost keeps solar energy from competing with other cheaper energy sources.

Other Applications

In almost every system powered by electricity, solar energy can play a central role without endangering the environment. Although this technology is presently more expensive to use than coal, natural gas, or petroleum, this difference in cost could change soon.

Space

Its use has extended to probes and satellites so that today hardly any spacecraft are designed without solar panels.



Transportation

The great challenge. Many prototypes of solar cars have been built, and some cities are already experimenting with buses.

Electronics

Calculators, watches, radios, flashlights, and so on. Almost any battery-powered device can be powered by solar energy.

Wind Energy

One of the most promising renewable energy resources is the use of wind to produce electricity by driving enormous wind turbines (windmills). Eolic power is an inexhaustible, clean, nonpolluting source of energy with more advantages than disadvantages. The most important disadvantages are our inability to predict precisely the force and direction of winds and the possibly negative impact that groups of large towers could have on the local landscape.

The Turbine

converts the wind into electrical energy through the use of simple technology based on mechanical gears.

1 The wind
moves the blades of the wind turbine, producing mechanical energy, which is then converted into electrical energy.

Brakes
are activated when the winds surpass 74 miles per hour (120 km/h), preventing damage to the wind turbine.

Low-speed axle
turns slowly, between 20 to 35 revolutions per minute (rpm).

Multiplier
With gears, it multiplies by 50 the speed of rotation of the high-speed axle.

High-speed axle
turns at around 1,500 rpm, allowing it to operate the generator.

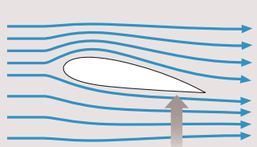
Generator
produces electric energy from the mechanical energy of the axle.

Computer
controls the conditions of the wind turbine and its orientation.

Blades
measure, on average, 130 feet (40 m) in length. Three-blade rotors have proven to be the most efficient design.

Cooling system
cools the generator with a fan. Also uses oil to cool the multiplier lubricant.

The blades
are movable. They can be oriented both to take maximum advantage of the wind and to slow down the turbine when the winds are too strong.

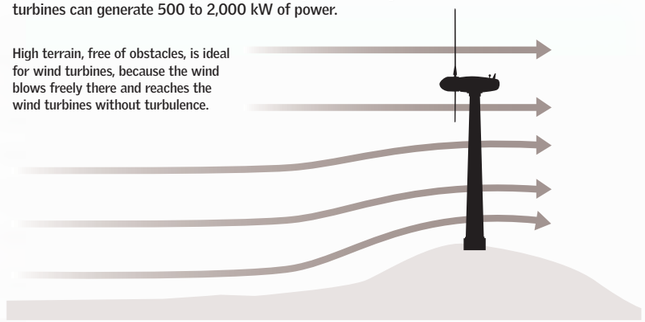


When facing the wind, their shape causes a pressure difference between the two faces of the wind turbine's blades. The pressure on the blades produces a force that turns the rotor.

Wind Turbines

These modern, large wind turbines, between 150 and 200 feet (45 and 60 m) high, tend to be grouped in windy, isolated, mostly deserted regions. The most modern wind turbines can generate 500 to 2,000 kW of power.

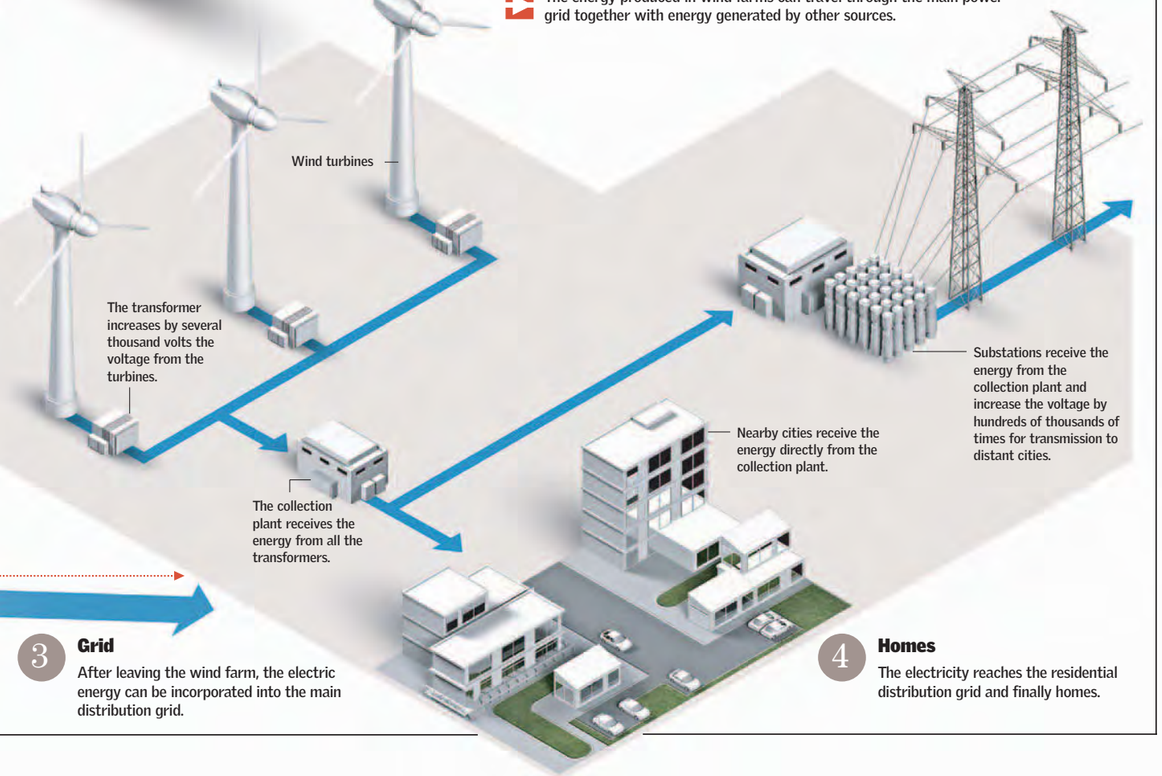
High terrain, free of obstacles, is ideal for wind turbines, because the wind blows freely there and reaches the wind turbines without turbulence.



The wind turbines are grouped into wind farms to maximize the potential of transmitting energy from only one location. This has the advantage of lowering costs and reducing environmental impact on the landscape.

The Journey of Electricity

The energy produced in wind farms can travel through the main power grid together with energy generated by other sources.



74,000
megawatts is the installed capacity of wind farms in the world. The leading country is Germany, followed by Spain and the United States.

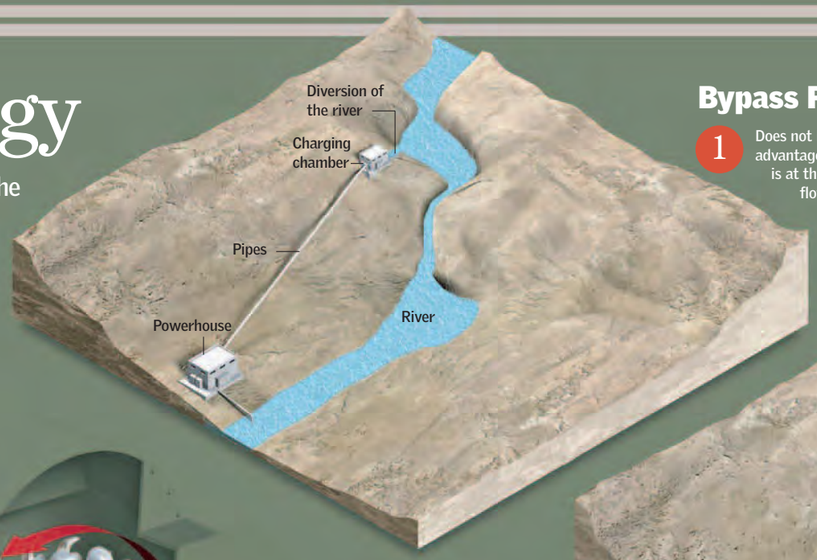
2 Energy
The electric energy produced by the generator goes down the cables to a converter.

3 Grid
After leaving the wind farm, the electric energy can be incorporated into the main distribution grid.

4 Homes
The electricity reaches the residential distribution grid and finally homes.

Hydroelectric Energy

About 20 percent of the world's electricity is generated by the force of rivers through the use of hydroelectric power plants. This technology, used since the 19th century, employs a renewable, nonpolluting resource, although the technology's impact on the environment is high. According to the United Nations, two thirds of the world's hydroelectric potential is being used, especially in North America and Europe.



Bypass Plant

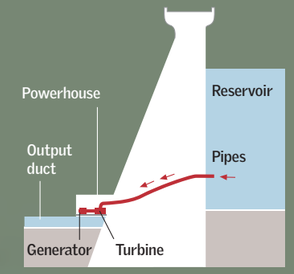
1 Does not have a reservoir. It simply takes advantage of the available flow of water and thus is at the mercy of seasonal variations in water flow. It also cannot take advantage of occasional surplus water.

Plants with Reservoirs

2 The presence of a reservoir, formed by a containment dam, guarantees a constant flow of water—and, therefore, of energy—independent of variations in water level.

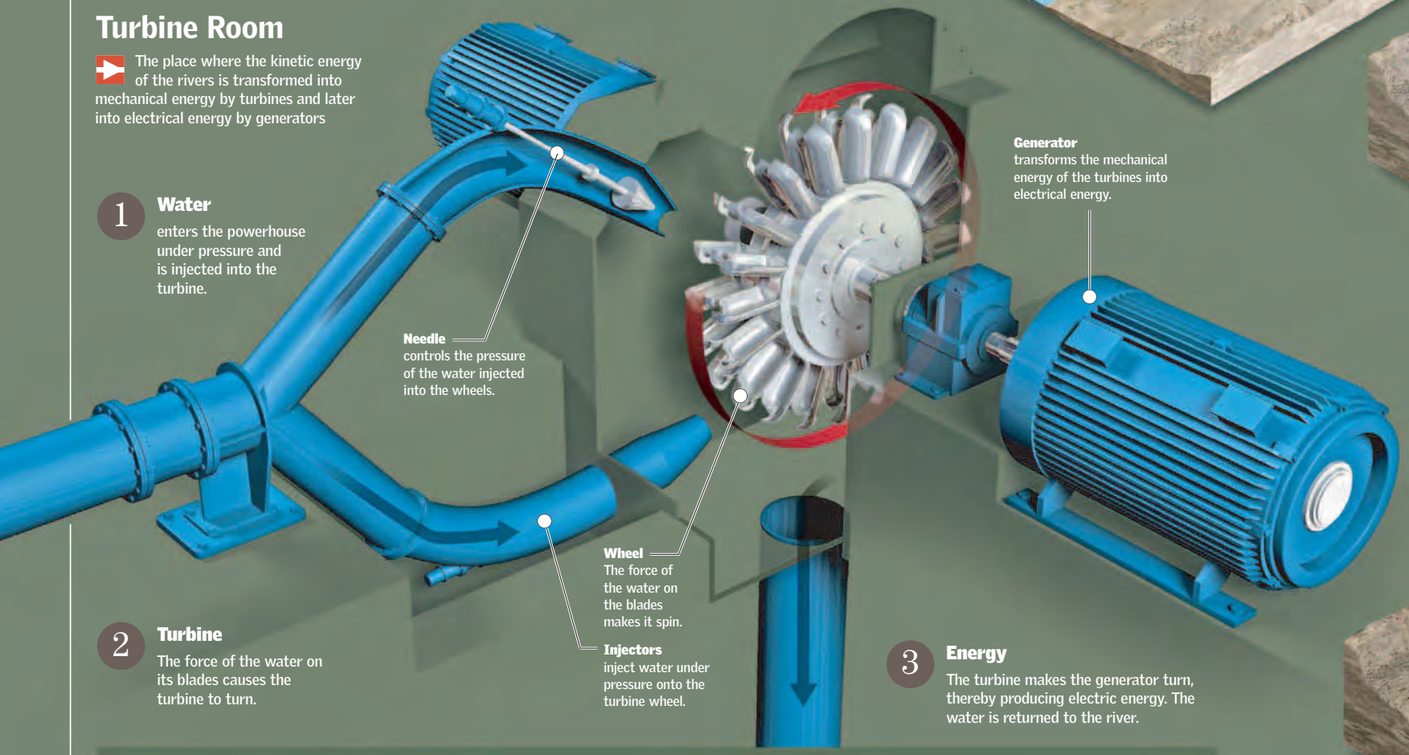
1 The water enters the powerhouse and turns the turbines. The generators produce electricity.

2 Once used, the water is returned to the river.



Turbine Room

The place where the kinetic energy of the rivers is transformed into mechanical energy by turbines and later into electrical energy by generators



1 **Water**
enters the powerhouse under pressure and is injected into the turbine.

2 **Turbine**
The force of the water on its blades causes the turbine to turn.

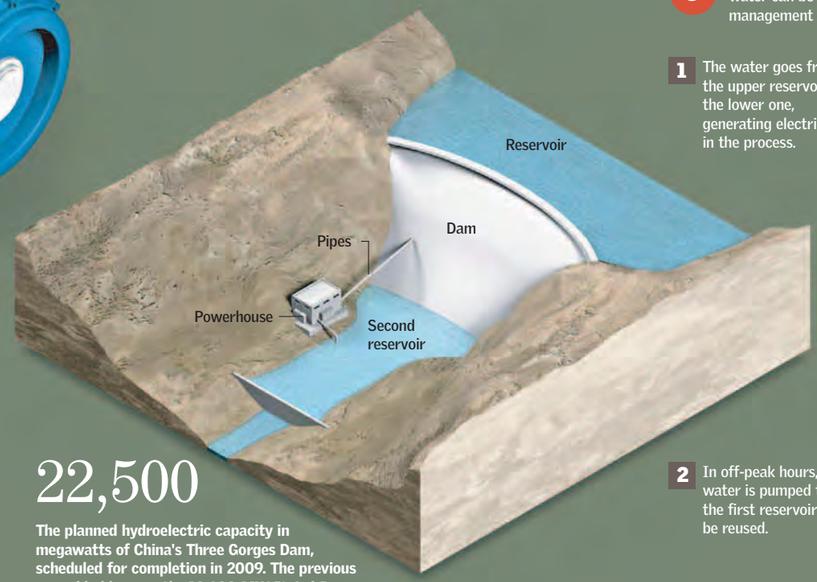
3 **Energy**
The turbine makes the generator turn, thereby producing electric energy. The water is returned to the river.

China

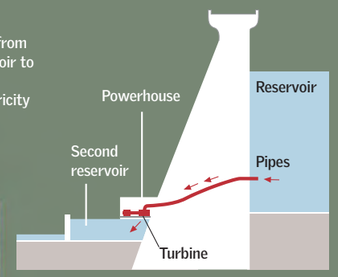
The world's largest producer of hydroelectricity (95,000 MW installed), followed by the United States, Canada, and Brazil

Pumping Plant

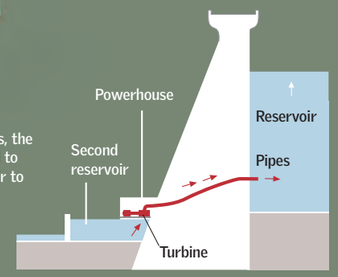
3 has two reservoirs located at different levels. In this way, the water can be reused, which allows a more efficient management of water resources.



1 The water goes from the upper reservoir to the lower one, generating electricity in the process.



2 In off-peak hours, the water is pumped to the first reservoir to be reused.



22,500

The planned hydroelectric capacity in megawatts of China's Three Gorges Dam, scheduled for completion in 2009. The previous record holder was the 12,600-MW Itaipú Dam on the border between Paraguay and Brazil.

From the Dam to the City

Electricity generated by the power plant is sent to a transformer, where its voltage is increased for transmission.

The electrical energy circulates through high-voltage power grids over great distances.

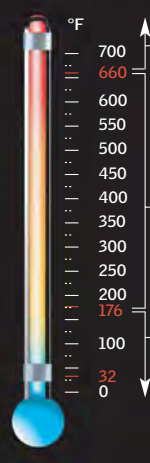
A transformer lowers the voltage of the electricity before distributing it to homes.

Geothermal Energy

Is one of the cleanest and most promising sources of energy. The first geothermal plant started operating more than 100 years ago. Geothermal plants generate electricity from the heat that emanates from the Earth's interior. Geothermal power plants, however, suffer from some limitations, such as the fact that they must be constructed in regions with high volcanic activity. The possibility of this kind of plant becoming defunct due to a reduction in such volcanic activity is always present.

Types of Geothermal Deposits

Geothermal deposits are classified by their temperature and by the resource they provide (water or steam).



Dry-Steam Deposits

They are the most efficient, although the least common. They produce steam at high temperature and pressure.

High-Temperature Deposits

The greater the temperature of the water in the deposit, the greater the efficiency of the plant in producing electric energy. Those of medium-high temperatures require binary-cycle power plants.

Low-Temperature Deposits

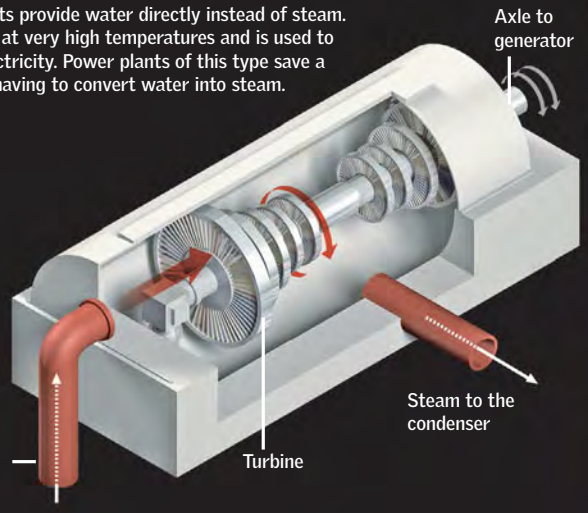
With temperatures lower than 176° F (80° C), they are useful for meeting domestic needs, such as heating or producing agricultural commodities.

Types of Power Plants

Not all geothermal power plants are the same. Their characteristics depend on the type of geothermal deposit from where the resource is extracted.

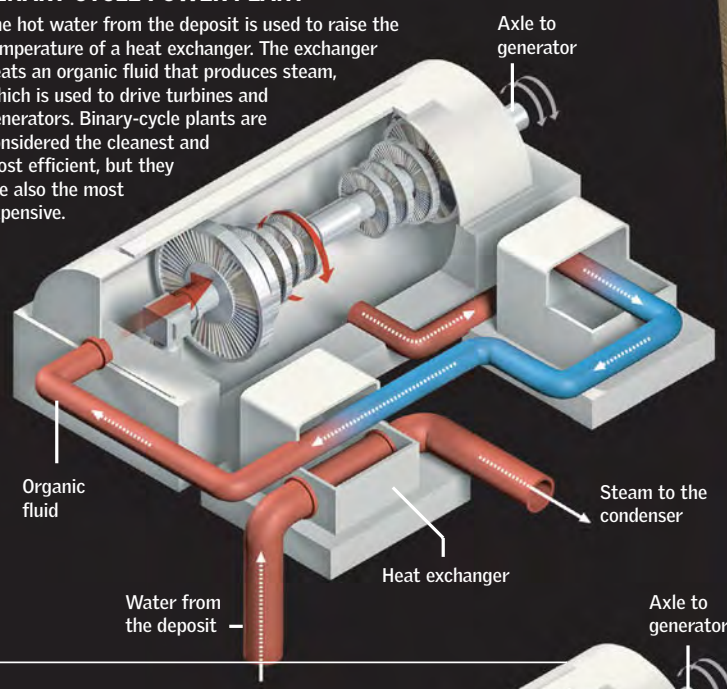
DRY-STEAM POWER PLANT

Some deposits provide water directly instead of steam. The water is at very high temperatures and is used to generate electricity. Power plants of this type save a step by not having to convert water into steam.



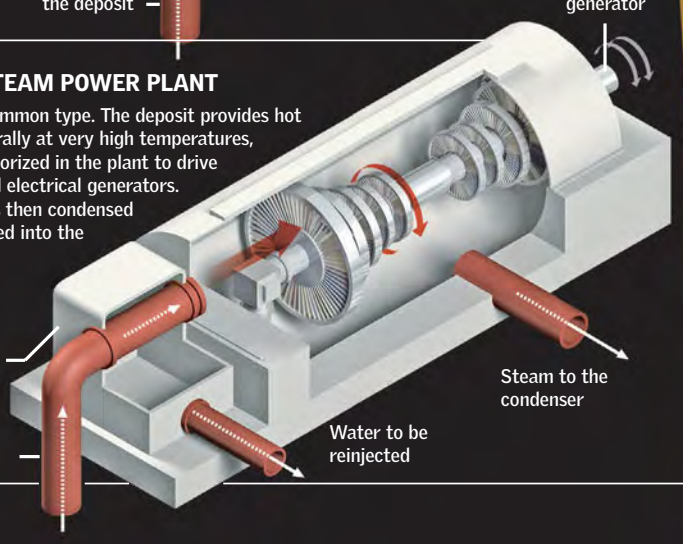
BINARY-CYCLE POWER PLANT

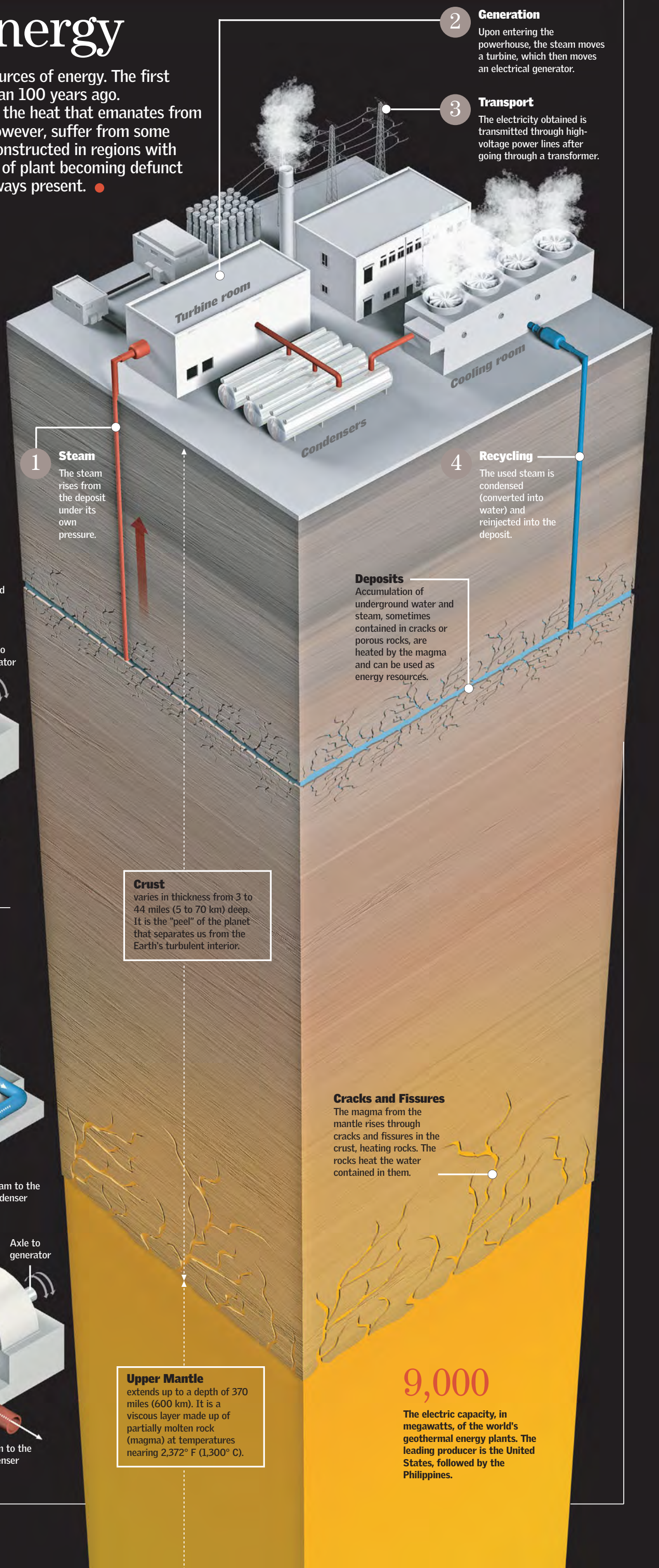
The hot water from the deposit is used to raise the temperature of a heat exchanger. The exchanger heats an organic fluid that produces steam, which is used to drive turbines and generators. Binary-cycle plants are considered the cleanest and most efficient, but they are also the most expensive.



FLASH-STEAM POWER PLANT

The most common type. The deposit provides hot water, generally at very high temperatures, which is vaporized in the plant to drive turbines and electrical generators. The water is then condensed and reinjected into the deposit.





2 Generation
Upon entering the powerhouse, the steam moves a turbine, which then moves an electrical generator.

3 Transport
The electricity obtained is transmitted through high-voltage power lines after going through a transformer.

1 Steam
The steam rises from the deposit under its own pressure.

4 Recycling
The used steam is condensed (converted into water) and reinjected into the deposit.

Deposits
Accumulation of underground water and steam, sometimes contained in cracks or porous rocks, are heated by the magma and can be used as energy resources.

Crust
varies in thickness from 3 to 44 miles (5 to 70 km) deep. It is the "peel" of the planet that separates us from the Earth's turbulent interior.

Cracks and Fissures
The magma from the mantle rises through cracks and fissures in the crust, heating rocks. The rocks heat the water contained in them.

Upper Mantle
extends up to a depth of 370 miles (600 km). It is a viscous layer made up of partially molten rock (magma) at temperatures nearing 2,372° F (1,300° C).

9,000

The electric capacity, in megawatts, of the world's geothermal energy plants. The leading producer is the United States, followed by the Philippines.

Tidal Energy

The variations in the tides and the force of the oceans' waves signify an enormous energy potential for generating electricity without emitting polluting gases into the atmosphere or depleting resources, as happens in the case of fossil fuels. Tidal plants are similar to hydroelectric plants. They have a water-retention dam (which crosses an estuary from shore to shore) and a powerhouse where the turbines and generators to produce electricity are located.

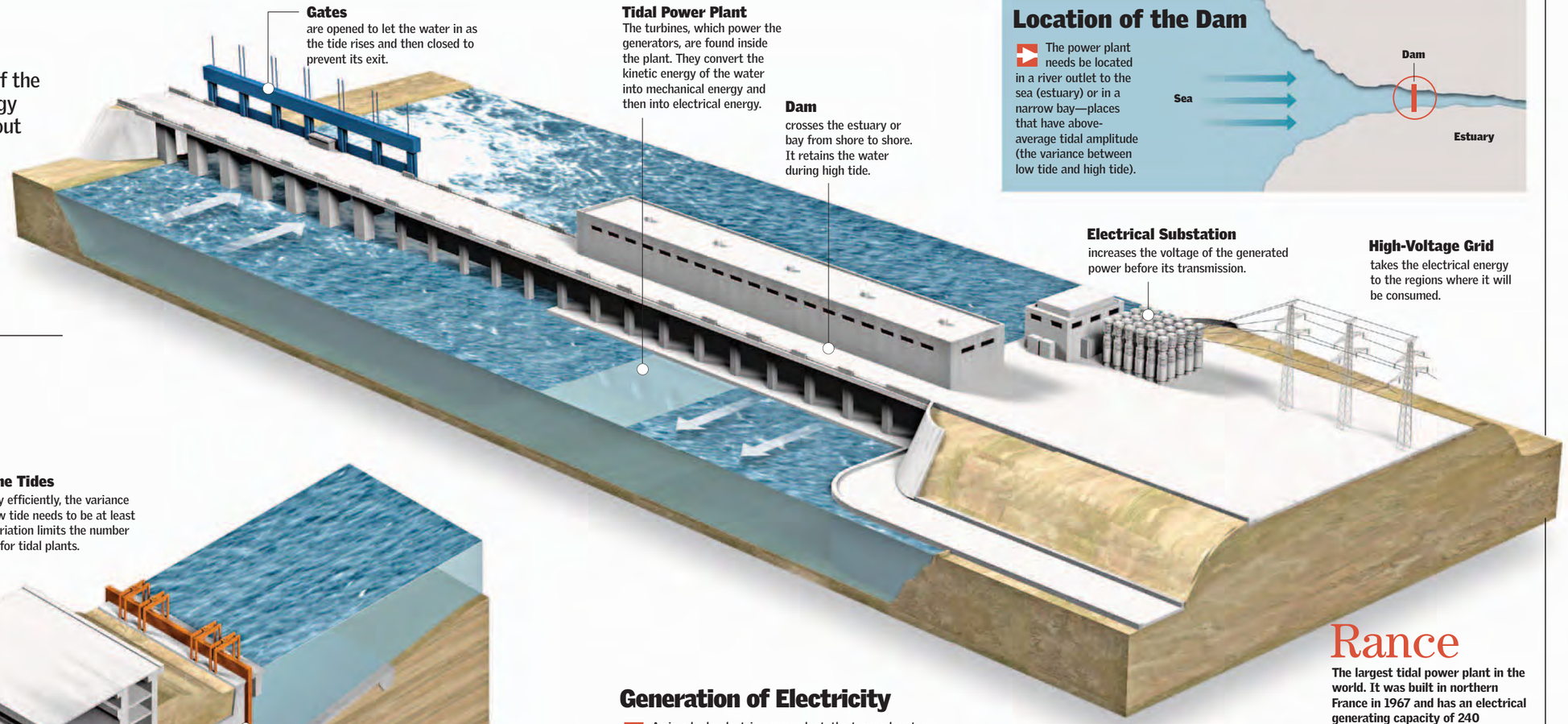
The Tides

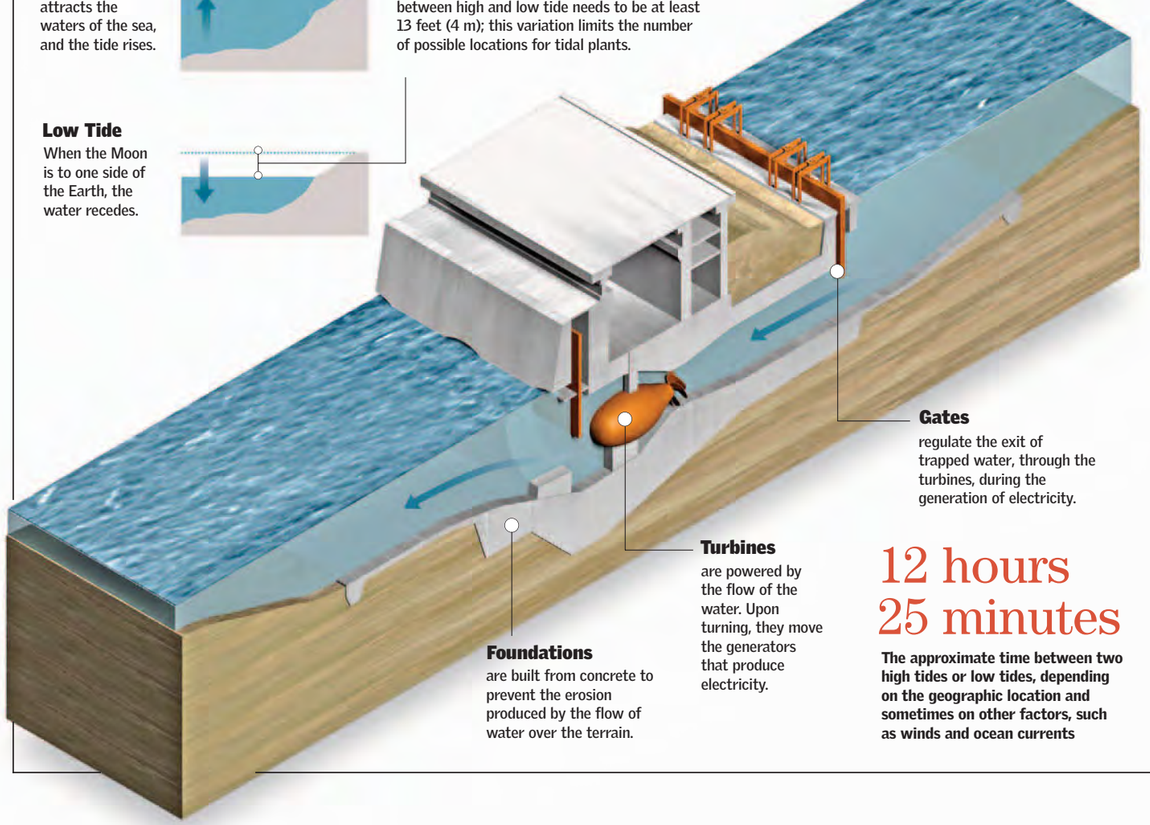
Responding to the Moon's gravitational pull on the Earth, the oceans' tides rise and fall twice a day.

High Tide
The Moon attracts the waters of the sea, and the tide rises.

Low Tide
When the Moon is to one side of the Earth, the water recedes.

Amplitude of the Tides
To produce electricity efficiently, the variance between high and low tide needs to be at least 13 feet (4 m); this variation limits the number of possible locations for tidal plants.





12 hours 25 minutes

The approximate time between two high tides or low tides, depending on the geographic location and sometimes on other factors, such as winds and ocean currents

Location of the Dam

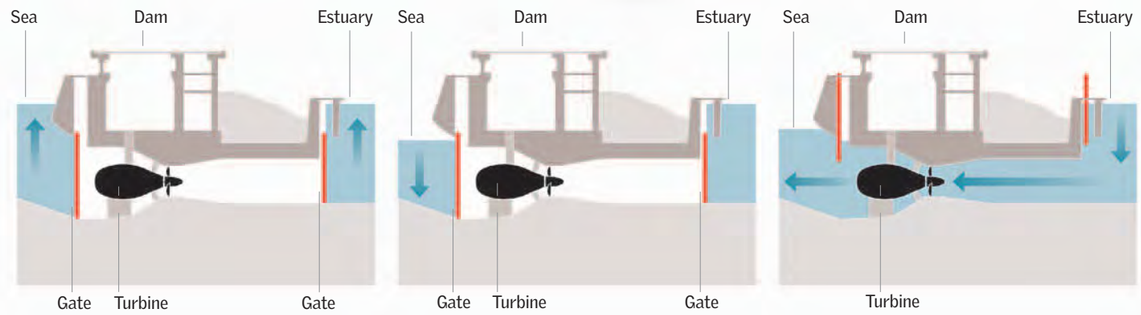
The power plant needs be located in a river outlet to the sea (estuary) or in a narrow bay—places that have above-average tidal amplitude (the variance between low tide and high tide).

Rance

The largest tidal power plant in the world. It was built in northern France in 1967 and has an electrical generating capacity of 240 megawatts.

Generation of Electricity

As in a hydroelectric power plant, the trapped water turns a turbine that operates the generators.



1 **High Tide**
During high tide, the level of the water rises in the estuary. The gates of the dam are opened to let the water in.

2 **Water Reservoir**
Once high tide is complete, the water level in the estuary begins to drop. The gates of the dam are closed to prevent the trapped water from escaping.

3 **Generation**
During low tide, the trapped water is released and it passes through the system of turbines that power the electrical generators.

Biodigesters

When anaerobic bacteria (bacteria that do not require oxygen to live) decompose organic material through processes such as rotting and fermentation, they release biogas that can be used as an energy resource for heating and for generating electricity. They also create mud with very high nutritional value, which can be used in agriculture or fish production. This technology appears promising as an energy alternative for rural and isolated regions, where, in addition to serving the energy needs of the populace, it helps recycle organic wastes.

The Reactor

is a closed chamber where the bacteria break down the waste. The generated gas (called biogas) and the fertilizing mud are collected for later use.

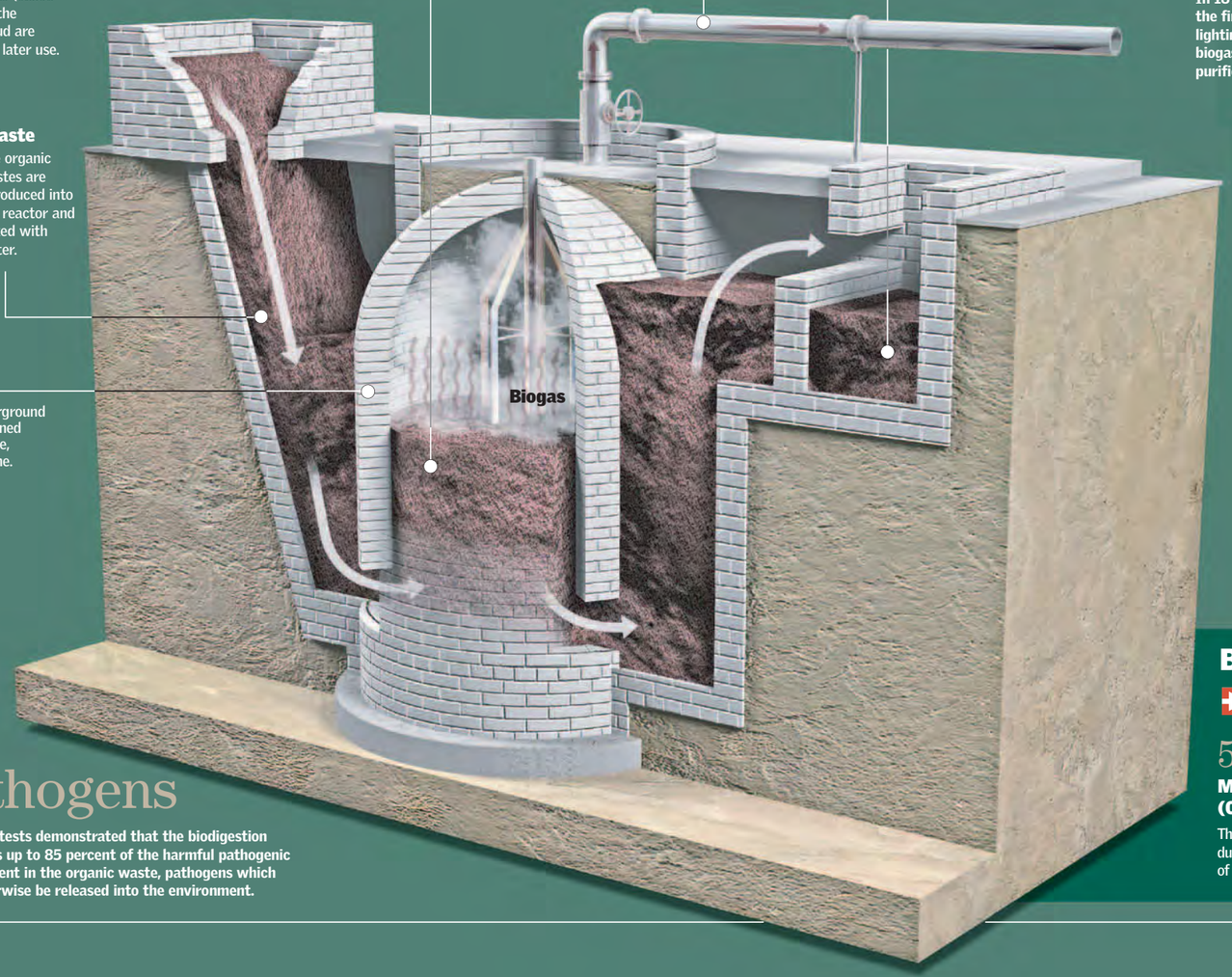
1 Waste
The organic wastes are introduced into the reactor and mixed with water.

2 Digestion chamber
Where the bacteria ferment the waste. They produce gas and fertilizing mud.

3 Biogas
is a product of the process that contains methane and carbon dioxide. It is used for cooking, heating, and generating electricity.

4 Fertilizing mud
Very rich in nutrients and odorless, it is ideal for agricultural uses.

Dome
is built underground and can be lined with concrete, brick, or stone.

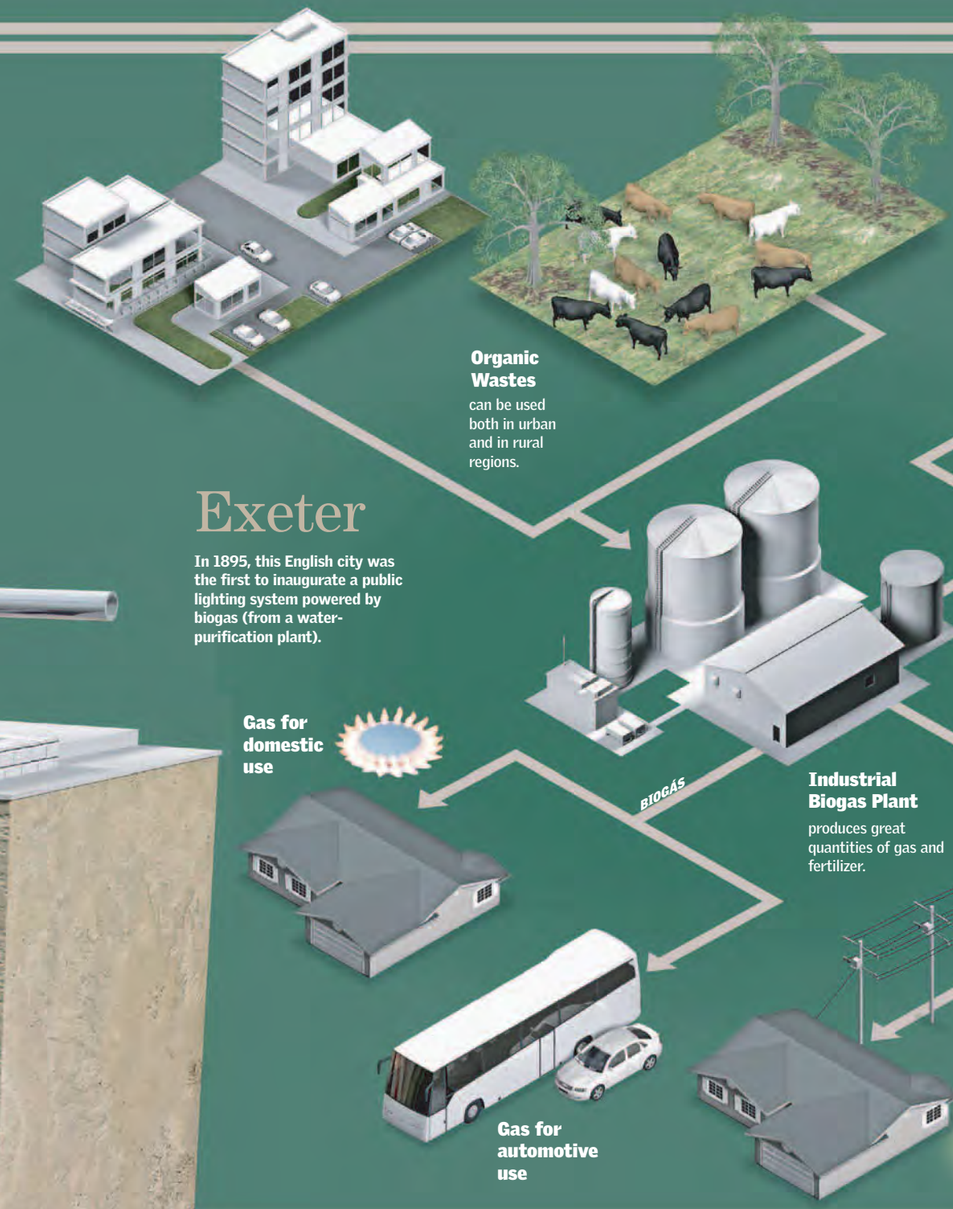


Pathogens

Laboratory tests demonstrated that the biodigestion process kills up to 85 percent of the harmful pathogenic agents present in the organic waste, pathogens which would otherwise be released into the environment.

Ecological Cycle

Through recycling, biodigester technology offers an alternative to the problem of organic trash, with which more and more large cities and agro-industries must contend.



Exeter

In 1895, this English city was the first to inaugurate a public lighting system powered by biogas (from a water-purification plant).

Biogas

The gaseous product of biodigestion, it is made up of a mixture of gases whose makeup depends on the composition of the wastes and the break-down process.

55-70% Methane (CH_4)
The energy-producing component of biogas

30-45% Carbon Dioxide (CO_2)
A greenhouse gas. It must be removed from biogas for certain uses.

1-10% Hydrogen (H_2)
Gas present in the atmosphere

0.5-3% Nitrogen (N_2)
Gas present in the atmosphere

0.1% Sulfuric Acid (H_2S)
Corrosive and highly polluting agent. It has to be removed.

Equivalencies

1 lb biogas + 1 lb biogas + 1 lb biogas = 1 lb gasoline

The energy potential contained in one pound of gasoline can be obtained from three pounds of organic wastes.

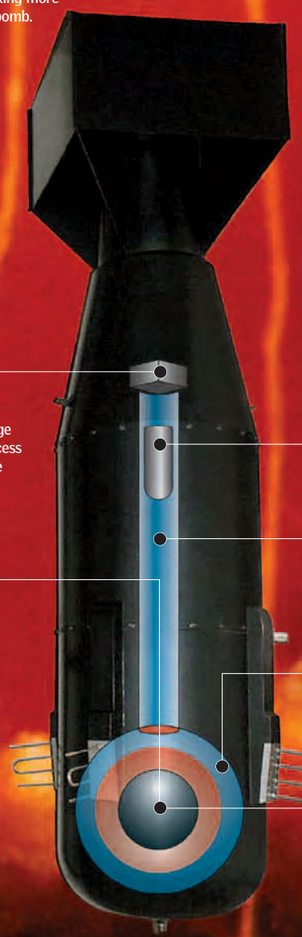
Fission and Chain Reaction

This weapon of mass destruction derives its energy from nuclear reactions. It was used for the first time against Japan, marking the end of World War II and the destruction of the cities of Hiroshima and Nagasaki. In addition to the massive loss of human life at the moment of detonation, many cases of cancer and genetic repercussions followed in the adjacent areas affected by radioactivity. Apparently the horror of witnessing what an atomic bomb could do was not enough, as today many countries have atomic arsenals even more powerful than the bombs used in 1945. ●

The Hiroshima Bomb

It exploded on August 6, 1945, at a height of 1,870 feet (570 m) over the downtown of this Japanese city, taking more than 70,000 lives. It was a fission bomb.

Name	Little Boy
Type	Fission
Power	14.5 kilotons
Weight	4.4 tons



1 DETONATION
An altimeter determines the appropriate height for the explosion and detonates a charge of common explosives; this process impels the projectile toward the atomic explosive.

2 REACTION
The projectile travels through the gun tube and impacts the uranium-235 contained inside the generator. This is what initiates the nuclear chain reaction.

3 EXPLOSION
The chain reaction occurs in a fraction of a second, releasing enormous amounts of energy as heat and lethal radiation.

WARHEAD
Made of uranium-235, it is highly fissile.

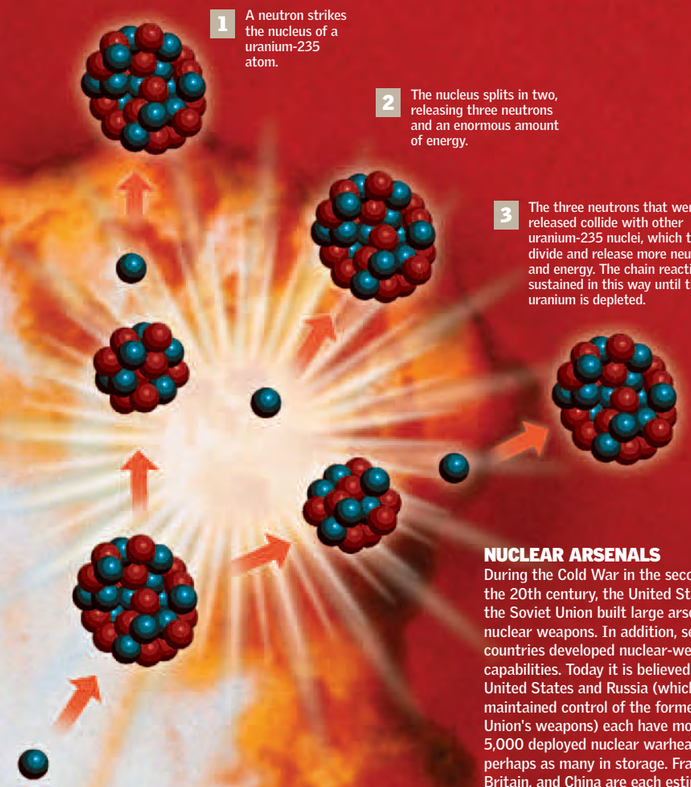
GUN TUBE

COMPRESSOR
concentrates the chain reaction so that the greatest amount of atomic explosive can undergo fission before the explosion.

ATOMIC EXPLOSIVE
Compact sphere of uranium-235. Its power equals 14,500 tons of TNT (trinitrotoluene).

Fission and Chain Reaction

Nuclear fission divides the nucleus of the uranium atom by bombarding it with neutrons.



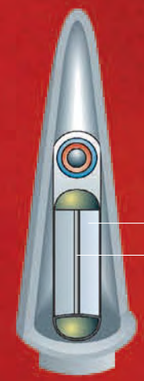
1 A neutron strikes the nucleus of a uranium-235 atom.

2 The nucleus splits in two, releasing three neutrons and an enormous amount of energy.

3 The three neutrons that were released collide with other uranium-235 nuclei, which then divide and release more neutrons and energy. The chain reaction is sustained in this way until the uranium is depleted.

The Fusion Bomb

Even more powerful atomic bombs use a different type of nuclear reaction—the fusion of hydrogen. That is why they are also known as hydrogen bombs. They have a power of up to 9,000 kilotons.



1 DETONATION
A small atomic fission bomb explodes, generating large amounts of heat inside the container.

2 REACTION
The heat compresses the deuterium (hydrogen isotope) against the rod of plutonium, causing fusion.

3 EXPLOSION
The fusion of deuterium takes place in a fraction of a second, causing the explosion.

NUCLEAR ARSENALS

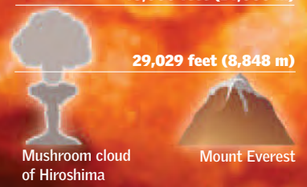
During the Cold War in the second half of the 20th century, the United States and the Soviet Union built large arsenals of nuclear weapons. In addition, several other countries developed nuclear-weapon capabilities. Today it is believed that the United States and Russia (which maintained control of the former Soviet Union's weapons) each have more than 5,000 deployed nuclear warheads with perhaps as many in storage. France, Britain, and China are each estimated to have more than 100 nuclear weapons. India and Pakistan have publicly tested nuclear weapons and may have more than a dozen each.

DAMAGE SCALE

Comparison between two nuclear explosions of differing power

THE ATOMIC MUSHROOM CLOUD

is formed by the shock wave, which absorbs the dust of everything that was burned.



Uses and Applications

MOBILITY FOR ALL
The assembly lines developed by Henry Ford for his Model T ended the idea of automobiles as luxury items and made them accessible to all.

DOPPLER RADAR 64-65
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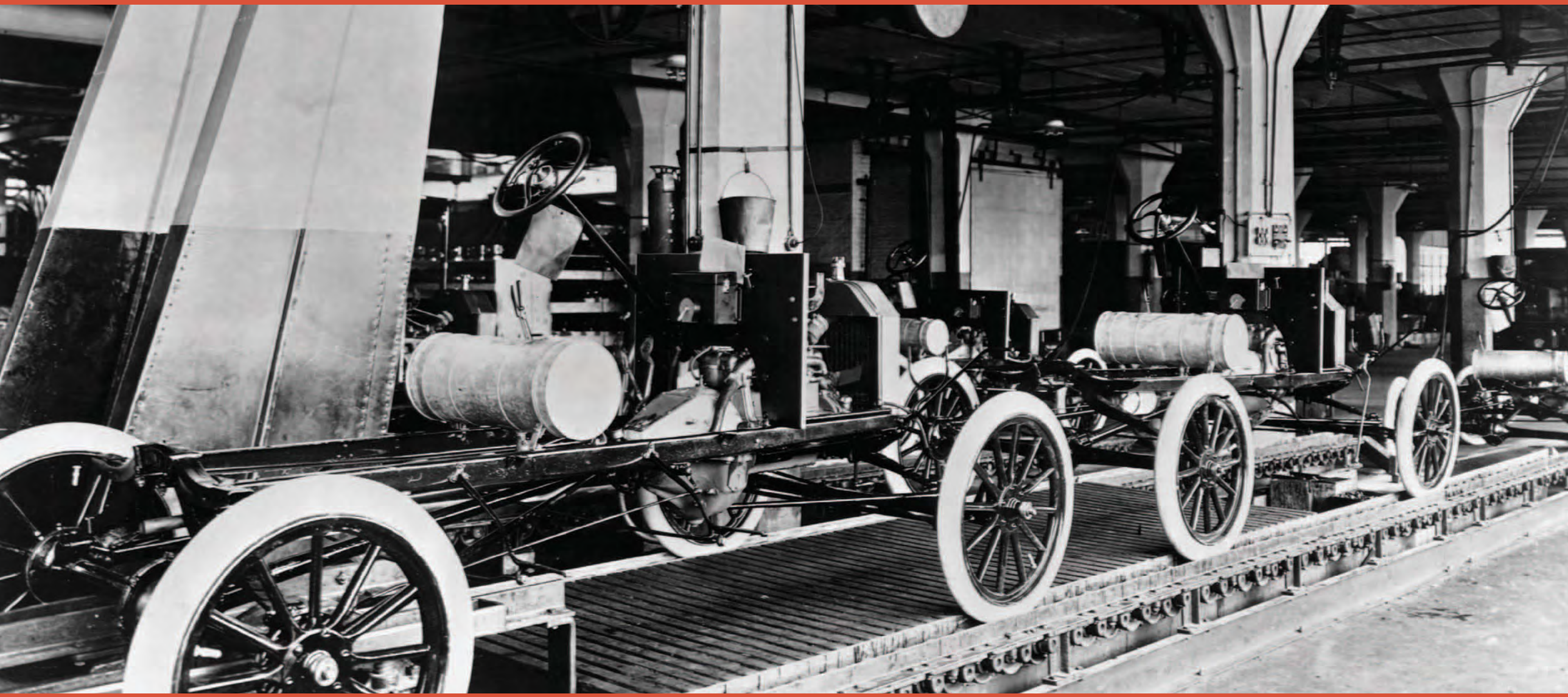


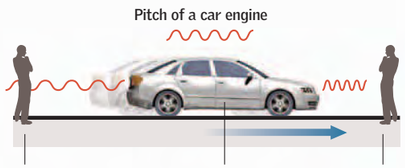
Human beings are nomadic by nature, thus their desire to explore made them develop efficient means of transportation that covered great distances very early in their history. However, it has been only in the past few centuries, as inventors began to make use of new scientific knowledge, that such machines have flourished. These new means of transportation made further discoveries possible, which in turn gave rise to even newer means of transportation, and so on. From sailing ships, which move with the wind, to ocean liners, from extremely efficient bicycles to powerful trains, we present to you the types of transportation that have made history. ●

Doppler Radar

The radar's effective range and use of the Doppler effect—a physical phenomenon postulated in 1842—create an efficient system able to detect moving objects from afar. Doppler radars can determine the speed and direction of a target, making these machines ideal for both civil and military purposes. The introduction of Doppler radars revolutionized meteorology, allowing humans to follow every development of storm patterns for the first time in history and helping people respond quickly and safely to many kinds of natural disasters.

The Doppler Effect

Whenever any kind of electromagnetic-wave generator/receiver is turned on, it vibrates, and the waves it emits differ in wavelength from those it receives. This phenomenon is known as the Doppler effect.



Person 1
As the source of the wave moves away from the listener, the wavelength increases with respect to the listener, and the pitch decreases.

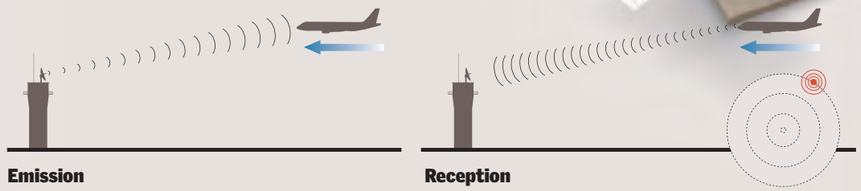
Conductor
always hears the same pitch, because it comes from a constant distance.

Person 2
As the source of the wave approaches the listener, the wave's pitch increases.

AIRPLANES
are equipped with Doppler radars that inform pilots about areas of heaviest precipitation in storm clouds so that the pilot can choose the safest route to the aircraft's destination.

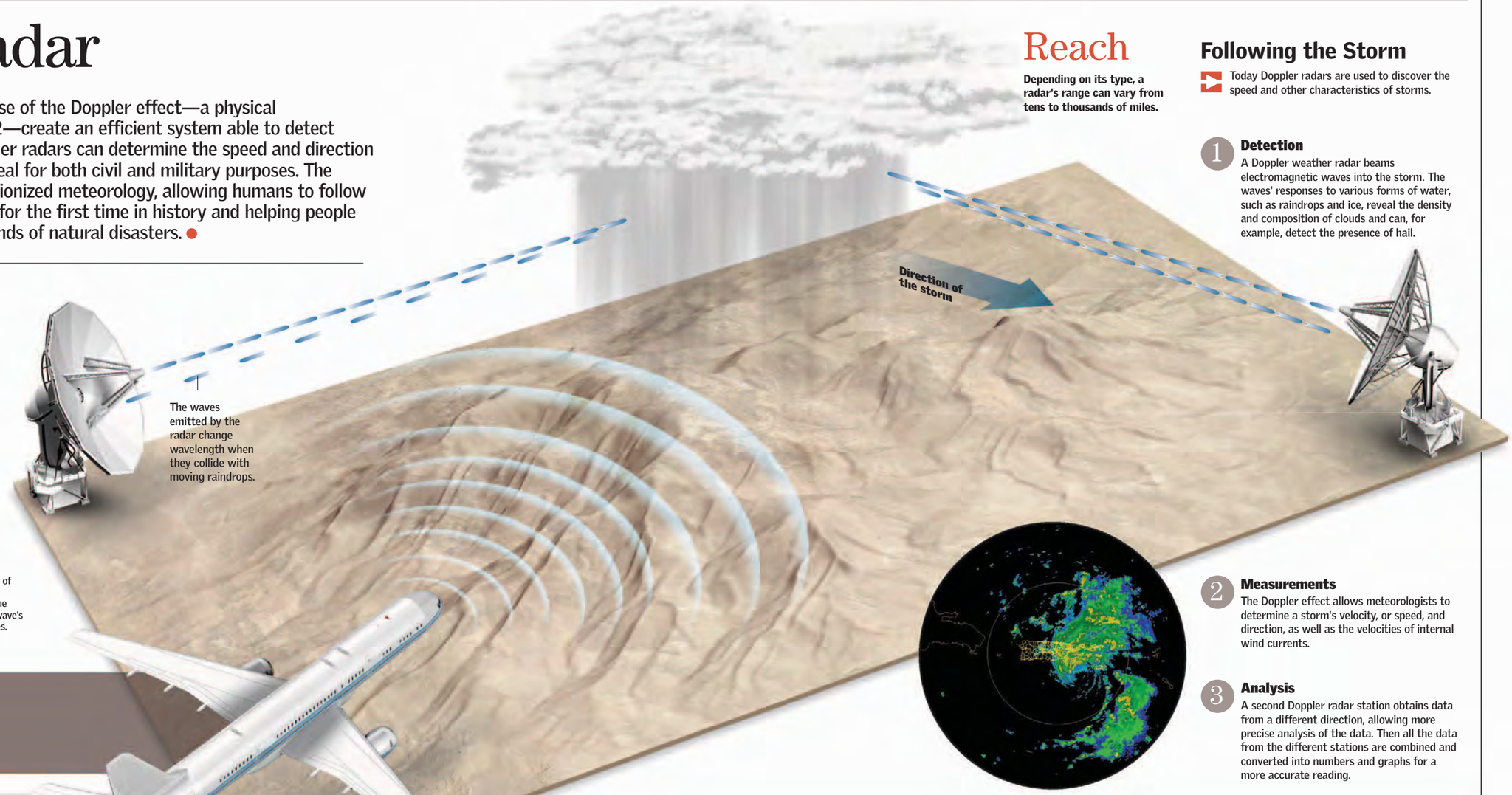
How Doppler Radar Works

Doppler radar interprets changes in the wavelength of the radio waves it emits. These changes in wavelength are caused when the waves sent from the radar are reflected by a moving object.



Emission
The radar emits radio waves of a known wavelength. If the waves encounter an object, they are reflected.

Reception
The waves reflected from a moving object change wavelength, which the radar correctly interprets as movement.



Reach

Depending on its type, a radar's range can vary from tens to thousands of miles.

Following the Storm

Today Doppler radars are used to discover the speed and other characteristics of storms.

1 Detection
A Doppler weather radar beams electromagnetic waves into the storm. The waves' responses to various forms of water, such as raindrops and ice, reveal the density and composition of clouds and can, for example, detect the presence of hail.

2 Measurements
The Doppler effect allows meteorologists to determine a storm's velocity, or speed, and direction, as well as the velocities of internal wind currents.

3 Analysis
A second Doppler radar station obtains data from a different direction, allowing more precise analysis of the data. Then all the data from the different stations are combined and converted into numbers and graphs for a more accurate reading.

Bats

have a type of biological Doppler radar. They emit sound waves, which bounce off possible prey, allowing the bats to determine an obstruction's speed and direction.

Other Applications

Doppler radars are used in anticollision systems of ships and airplanes and as portable traffic-control radars. Doppler radars are also used in medical, military, and underwater research, among other applications.

Traffic
Police use portable Doppler radars to monitor the speed of passing vehicles. Doppler radars are handy tools for verifying the speed of automobiles from any location.

Navigation
Ships and airplanes use Doppler radar systems to scan nearby traffic for possible collision risks. The radars work in tandem with automatic emergency exit systems.

Medicine
Doppler systems have been introduced in diagnostic ultrasound scanning. They can provide visual feedback of movements within the body, as in the circulatory system—even in the heart and brain.

Crash Test Dummies

To assess the risks that automobile passengers could experience in collisions, mannequins—designed to resemble human beings of different sizes and weights—are used. They are fitted with aluminum bones and muscles, as well as with rubber skin. These dummies are equipped with sensors that collect data on every aspect of the collision (acceleration and deceleration effects, among other things). In this way, biomechanical engineers can evaluate possible injuries that real occupants of a vehicle could sustain in similar collisions. These robotic mannequins, which have helped to save many lives, are called crash test dummies. Even though dummies can "feel" (or virtually replicate and simulate human sensory perceptions), they have the advantage of not getting hurt the way humans could.

Anatomy in Action

The dummies have rubber skin, aluminum skeletons, and internal electronic sensors. In tests, dummies are dressed—to reduce friction—and protected by air bags and safety belts. The force of each impact is collected by a computer located in the vehicle's back seat. In a strong impact, dummies can have their "skin" cut, but only rarely are they damaged any more than this.

SAFETY FEATURES

AIR BAG
In a collision, 10.5 to 21 gallons (40 to 80 l) of air inflate the air bag in less than a tenth of a second.

SAFETY BELT
prevents passengers from being ejected from the vehicle or from being thrown onto the steering wheel, windshield, or front seat.

134 IS THE NUMBER OF DATA TYPES THAT CRASH TEST DUMMIES COLLECT.

DIFFERENT TYPES OF SENSORS

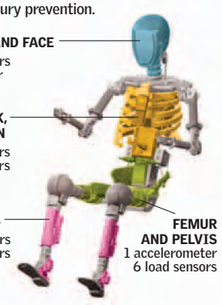
Crash test dummies are equipped with different types of tools—movement sensors, load sensors, accelerometers, and potentiometers—that indicate what happens when a person is in a collision. These mannequins collect data essential to injury prevention.

HEAD, NECK, AND FACE
9 accelerometers
1 potentiometer
7 load sensors

THORAX, BACK, AND ABDOMEN
5 accelerometers
3 potentiometers
1 load sensor

LOWER LIMBS
4 accelerometers
2 potentiometers
6 load sensors

FEMUR AND PELVIS
1 accelerometer
6 load sensors



Accelerometers
are designed to measure strong impacts. They contain small magnets that slide when the sensor moves, generating electrical charges that indicate changes in speed.

TRANSMISSION CABLES
carry information from the sensors to the computer.

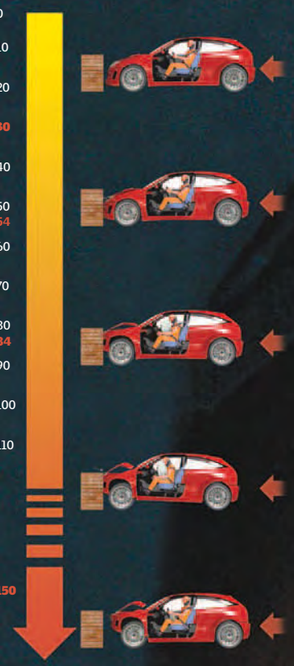
Movement sensors
generate a small voltage that measures the twisting of the body. The sensors located in this area record the speed and intensity of the compression of the chest.

Load sensors
measure the forces generated by a collision using small piezoelectric crystals that generate electricity by expanding and contracting. These crystals, located throughout the dummy's body, provide very useful data in assessing and preventing serious injuries.

COLLISION ACCORDING TO THE LAWS OF PHYSICS

The inertial forces in a collision are enormous. Energy is neither created nor destroyed; it is only transferred. Injuries sustained in a collision are the tangible effects of energy that could not be absorbed in any other fashion.

TIME IN THOUSANDTHS OF A SECOND



A ACCELERATION
Kinetic energy (energy being released) varies directly with the mass of the object. The kinetic energy of an industrial truck is greater than that of a small car. According to Newton, a body in motion will tend to continue in its motion unless it is acted upon by an outside force.

B INERTIA
In a collision, bodies inside the vehicle continue to move forward, because they resist changes to their motion. Safety belts counteract this inertia and help keep the driver and passengers in their seats. Air bags reduce the chance of possible injuries during collision when the body is propelled forward and hits the dashboard.

C ENERGY ABSORPTION
Newton's laws apply to the inside of a body just as much as to the outside. When a moving head encounters an obstruction, the head and its contents tend to keep moving forward, causing the brain to strike the inside of the cranial cavity—or the spleen to collide with the abdominal cavity.

A car with a mass of 2,200 pounds (1,000 kg), moving at 60 miles per hour (100 km/h), exerts 160,000 pounds (74,000 kg) of force during a collision.

5 LOAD SENSORS NEAR THE FACE

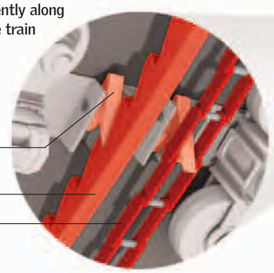
Roller Coasters

These colossal, twisted structures provide an exhilarating and frenetic ride. They wed technology to basic and seemingly incompatible emotions, such as panic, courage, fear, joy, vertigo, and amusement. Built as if to exclusively prove Newton's theories, the science of roller coasters abounds with all his terminology: acceleration, mass, gravity, movement, and inertia. But in all this, what is really thrilling is the free fall, the attraction of the abyss. ●

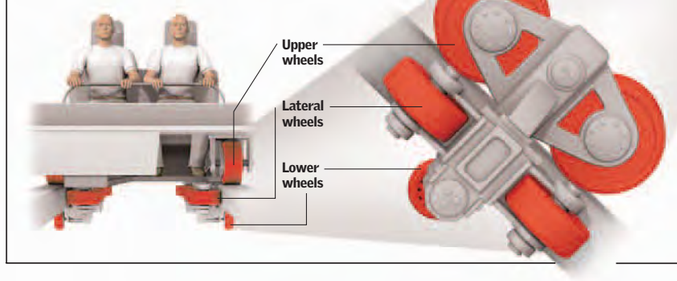
Safety Details

The designers of these extreme machines take into account all possible safety factors to provide as safe an experience as possible. Riders are made to wear safety belts, and machine parts are inspected on a regular basis to prevent accidents. Joints and beams are X-rayed for flaws. Safety devices applied to the drive chain before cars reach the top prevent the train of cars from moving backward. These devices are also installed on some of the hills, where the train slows down in its climb. In the event of wind gusts and sudden decelerations, these preventive measures keep the train in place and stop it from backtracking.

Special device
is located intermittently along the chain lift. As the train prepares for its descent, this device prevents it from moving backward.

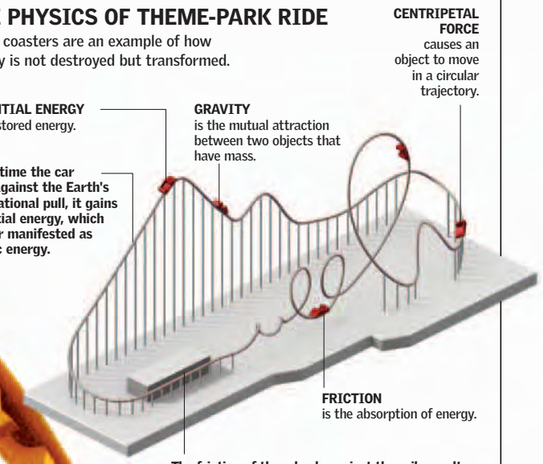


Wheels to keep the trolley on the track
Three types of wheels are needed: upper wheels to control the train for most of the route; lower ones for use on the hills—G forces are sometimes greater than the weight of the train; and lateral wheels to prevent the train from derailing on curves.



1912
marks the year John Miller designed the first underfriction roller coaster.

THE PHYSICS OF THEME-PARK RIDE
Roller coasters are an example of how energy is not destroyed but transformed.



1 POTENTIAL ENERGY
When the wagon reaches the highest point of the roller coaster, it has a great deal of potential energy.

2 MECHANICAL ENERGY
At a certain point in the trajectory, both energies (potential and kinetic) cancel each other out.

3 KINETIC ENERGY
is energy of motion—that is, the energy released by the train every time it descends.

Force of Gravity in Action

Most of the motion in a roller-coaster ride is a response to the Earth's gravitational pull. No engines are mounted on the cars. After the train reaches the top of the first slope—the highest point on the ride—the train rolls downhill and gains speed under the Earth's gravitational pull. The speed is sufficient for it to climb over the next hill. This process occurs over and over again until all the train's energy has been lost to friction and the train of cars slows to a stop. If no energy were lost to friction, the train would be able to keep running as long as no point on the track was higher than the first peak.

Acceleration

A body tends to remain at rest or in uniform motion unless acted upon by a force. Therefore, the forces a rider experiences in a roller coaster are actually the resistance of the body to changes in its motion, a property Newton called inertia.

128 miles per hour (206 km/h)
is the speed reached by Kingda Ka, the highest and fastest roller coaster. It is located in New Jersey.

Automobiles

The first attempts at manufacturing automobiles took place in China at the end of the 17th century, although the first recorded use of an automobile dates back to 1769, when Nicolas-Joseph Cugnot created a steam-propelled car. Karl Benz gave cars their current form in 1886. Since the introduction of the Model T assembly line, automobiles have not only changed the urban and rural landscape but also, most importantly, have completely transformed modern industry.

On the Inside

A number of complementary systems allow the cars to function. Sophisticated electronics and state-of-the-art design make today's models veritable mechanical jewels.

AIR BAG SYSTEM
inflates several flexible bags inside the car, absorbing much of the impact that riders are subjected to during a collision.

STEERING WHEEL
activates the steering mechanism that turns the front wheels.

DIFFERENTIAL
uses a system of gears to power both drive wheels equally even when they may have different rotation speeds (when curving, for example).

WINDSHIELD
is laminated to keep it from shattering during collision.

FUEL-INJECTION SYSTEM
electronically controls the amount of fuel injected into each cylinder.

BODYWORK
is designed to deform progressively in order to absorb as much energy as possible during a collision.

REAR SUSPENSION

MUFFLER
reduces the noise produced by gases as they exit the exhaust pipe.

FRONT SUSPENSION
Set of springs and shock absorbers that absorbs vibrations caused by uneven terrain

AIR INTAKE
The air that enters the engine passes through a filter before mixing with the gasoline.

RADIATOR
cools down the engine's coolant.

COMPRESSOR
activates the car's air-conditioning system.

ALTERNATOR
generates the energy consumed by the car's electrical devices.

WHEEL RIM
is made out of a lightweight alloy to lower the weight of the wheel.

TIRE
has a low profile, improving stability during fast turns.

DISK BRAKE
A brake pad attached to the wheel, it is gripped by the calipers when the brake pedal is depressed.

DRIVE SHAFT
Extension from the transmission connecting the gearbox to the drive wheels in cars with rear-wheel drive

EXHAUST PIPE
expels engine exhaust away from the vehicle.

ENGINE
Modern engines use fuel efficiently—consuming and polluting less than ever—and they can provide high power even with relatively small engines.

MASTER BRAKE CYLINDER
Activated by the pedal, it applies hydraulic pressure to the brake calipers, causing them to grip the wheels.

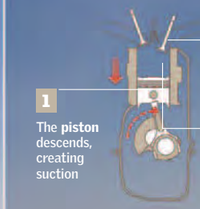
GEARBOX
Series of gears used to adjust the motor's speed of revolution to that of the drive wheels

CATALYTIC CONVERTER
modifies the harmful components of exhaust gases into less harmful emissions.

How the Engine Works

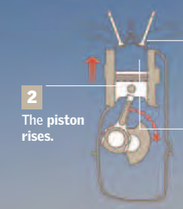
The development of cars began with the invention of the internal combustion engine. Its basic principle—the four-stroke engine created by the German Nikolaus Otto—has continued to be used to this day.

FIRST STROKE: INTAKE



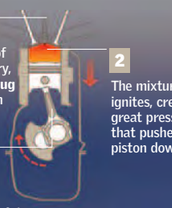
1. The **piston** descends, creating suction
2. The **intake valve** opens.
3. A mixture of air and gas enters the **cylinder.**

SECOND STROKE: COMPRESSION



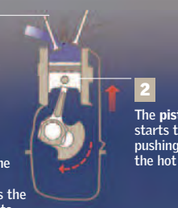
1. The **intake valve** closes.
2. The **piston** rises.
3. The mixture of air and gas is compressed into a more reduced space.

THIRD STROKE: POWER STROKE



1. At the end of the trajectory, the **spark plug** generates an electrical spark.
2. The mixture ignites, creating great pressure that pushes the piston down.
3. The force transmitted through the **piston shaft** causes the **crankshaft** to turn.

FOURTH STROKE: EXHAUST STROKE



1. The **escape valve** opens.
2. The **piston** starts to rise, pushing along the hot gases.
3. Once the piston reaches the top of its stroke, the **cycle** begins again.

1769
CUGNOT
built the first steam-propelled automobile. This vehicle reached about two miles per hour (3 km/h).

1883
DAIMLER
equipped a carriage with the first gasoline engine.

1899
RENAULT
Covered and with an internal steering wheel

1901
OLDSMOBILE
The first car produced in series in the United States

1913
FORD T
In 1917, Henry Ford used an assembly line to manufacture this car.

1934
CITRÖEN
The front-wheel drive is introduced.

1936
BEETLE
The first Volkswagen car was designed by Porsche at Hitler's request.

1948
FERRARI
The company presents its first street car, the 166 Sport.

1954
MERCEDES-BENZ 300 SL
Known as "Seagull Wings," it was the first car with a fuel-injection engine.

1955
FIAT 600
This popular compact city car is produced in Italy.

1964
CADILLAC DE VILLE
A spacious convertible, it was the ultimate in automobile luxury of its time.

2007
TOYOTA HYBRID X
A concept car with a sunroof, LED headlights, swiveling rear seats, and drive-by-wire controls

Trains

Although rail transportation dates back to ancient Greece (6th century BC), this technology has only recently (beginning of the 19th century) been used to its full potential. Trains were essential to the Industrial Revolution, and during their almost 200 years of existence, they have evolved into increasingly fast models. Some—such as the TGV (France), the Shinkansen (Japan), the AVE (Spain), and the Intercity 125 (United Kingdom)—travel faster than 185 miles per hour (300 km/h).

CONTROL CABIN

EMERGENCY EXIT

AIR DAM

LOCOMOTIVE
Equipped with powerful electric engines, the TGV's locomotives can travel at high speed even while climbing hills. Because the train has a locomotive at each end, the locomotive does not need to be repositioned before a trip in the other direction.

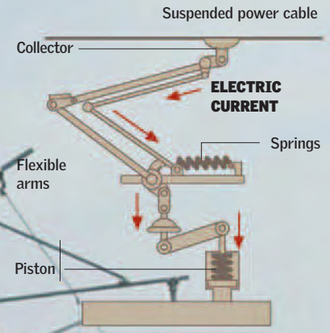
357.16 miles per hour (574.8 km/h)

IN A TEST RUN, A TGV REACHED THIS SPEED IN 2007, SETTING A NEW RAIL SPEED RECORD.

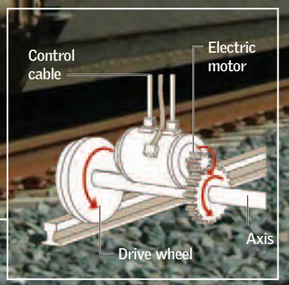
How It Works

High speeds were achieved because of aerodynamic designs, lighter and more powerful locomotives, and exclusive-use railway routes.

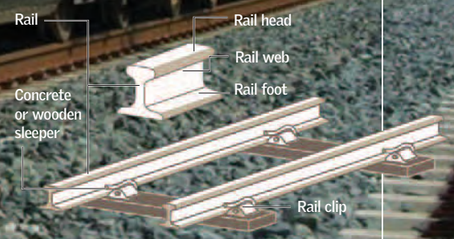
SOURCE OF ENERGY
Locomotives get 25,000 volts of electric energy from power cables through a pantograph, a mobile mechanism that travels with the train and keeps the electrical circuit alive.



DRIVE
Each wheel has an independent electric engine.



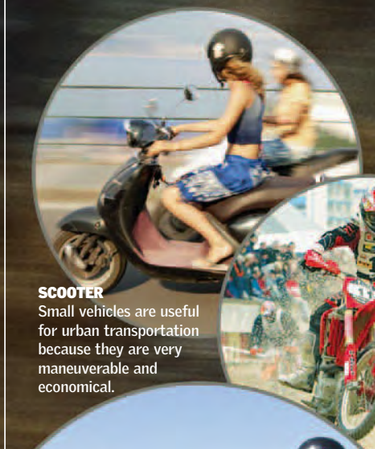
RAILS
The principle of rail travel has remained essentially the same for the past 150 years.



Motorcycles

These agile vehicles are commonly used in both transportation and racing. The first motorcycle was invented in 1885. During the 20th century, motorcycles became a symbol of youthfulness and rebellion. The first motorcycles were used for mail distribution. Special motorcycles were then manufactured for urban environments, racing, and tourism. Models with even faster and more powerful engines were also invented for those looking for extreme experiences on two wheels.

Some Types of Motorcycles

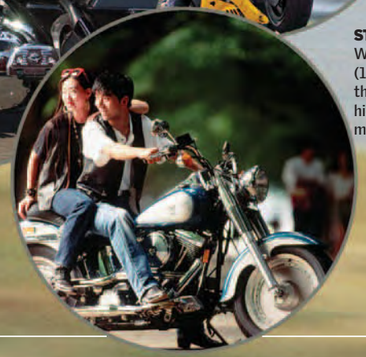


SCOOTER
Small vehicles are useful for urban transportation because they are very maneuverable and economical.

ENDURANCE
All-terrain motorcycles. They are used in the famous Paris-Dakar race.

ROAD
Very comfortable and designed to travel great distances on paved roads

STREET
With small engines (125 cc and 150 cc), these are economical, high-performance motorcycles.



RACE
Very powerful and equipped with the latest technology. They are used for high-level competitions.

Motorcycle for Tourism or Adventure

This model is one of the most versatile; it adjusts to mountain paths as well as to roads. Equipped with electronic innovations and a powerful engine, it is comfortable and can even carry loads.

CONTROL PANEL
is digital and has a liquid quartz display with an odometer, a clock, and a fuel gauge.

WINDSHIELD
On some models, windshields can be adjusted according to the driver's height.

MIRRORS

HEADLIGHTS
Two wide, shining multifaceted reflectors

WHEELS
are made of aluminum, which make them light and resistant to damage.

BRAKES
A dual braking system balances the front and rear brakes.

ENGINE

GEARBOX

SEAT

BAGGAGE COMPARTMENT

TURN SIGNAL

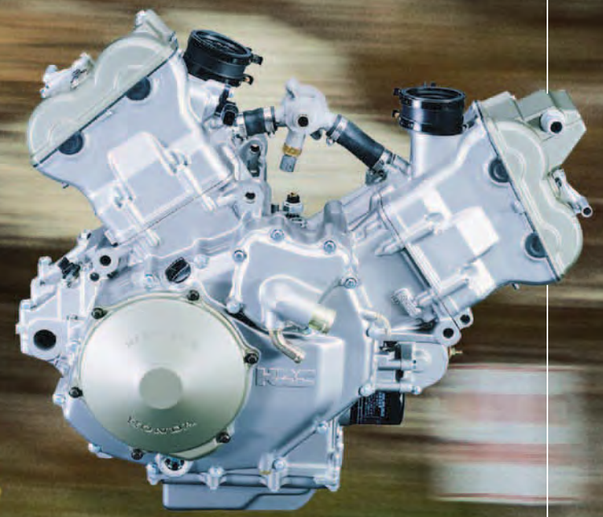
MUFFLER

FUEL TANK
is made of aluminum and has a capacity of 6.6 gallons (25 l).

FRAME
is dual-beam and made out of aluminum. It uses a central shock absorber to support the rear of the vehicle.

137 miles per hour (220 km/h) km/h

ENGINE
Two-cylinder, four-stroke engine



Engine capacity	61 cubic inches (996 cu cm)
Cylinders	V2
Valves	8
Gearbox	6 speeds

History

1885 TTHE FIRST
Built on a wooden frame by Gottlieb Daimler in Germany

1901 SINGLE
It has a 1.75 HP engine and a chain transmission, and it can reach 25 miles per hour (40 km/h).

1914 SINGLE RACING
An adjustable front suspension and an experimental electronic ignition have been added.

1916 POWERPLUS
With a sidecar (for passengers), it is the first motorcycle to use an engine with lateral valves.

1928 PRINCE
With 20 HP and three speeds, it reaches more than 46 miles per hour (75 km/h).

1946 CHIEF
In the postwar period, it was popular with police in New York City.

1988 HONDA GL 1500
A motorcycle is ideal for couples. It has a powerful engine and is almost as comfortable as an automobile.

2007 KAWASAKI
Its striking design highlights this model's joining of technology and aesthetics.

Bicycles

This two-wheel vehicle is not only a healthy, environmentally friendly, and economical means of transportation, but it is also extraordinarily efficient! Up to 99 percent of the energy a cyclist transfers to the pedals reaches the wheels. In fact, it is the most efficient load-bearing vehicle. Bicycles have played important sociocultural roles, giving rural and urban workers more mobility and symbolizing freedom during the first feminist movements.

How the Gear Shifter Works

Most chain wheels have 48 teeth. A complete turn moves 48 chain joints.

1 On flat terrain, the 12-toothed gear should be used, putting the bicycle in high gear.

2 By turning the chain wheel a quarter rotation, both the gear and the wheel make a complete turn.

3 When ascending, the 24-tooth gear should be selected, putting the bicycle into low gear.

4 With every half turn of the chain wheel, the gear makes one complete turn. In this way, the force thus transmitted doubles without any effort on the part of the cyclist. In other words, this force only travels half the distance every time the chain wheel completes one rotation.

TRACK BICYCLE

- Aerodynamic design for racing
- They do not have brakes.
- Made of aluminum and compound materials, such as carbon fibers and epoxy resins
- They do not have gears.

MOUNTAIN BIKE

- Reinforced frame. It can withstand the wear and tear of racing.
- Front and rear suspensions, which absorb irregularities in the terrain
- Multiple gear ratios
- Articulated frame

GEAR SELECTOR
uses the derailleur to select from the different speeds.

HANDLEBARS
allow the cyclist to guide the bicycle by changing the direction of the front wheel.

BRAKE CABLE

BRAKES
apply force to the rims and are activated from the handlebars by means of levers and cables.

FORK
connects the front wheel to the handlebars. Some models have shock absorbers.

SPOKES
They connect the rim to the hub, adding structural rigidity to the wheel with only a negligible addition of weight.

SPROCKETS
Set of gears with diameters that differ from those of the drive gear. They allow the wheel to turn at different speeds as the cyclist pedals at the same pace and level of effort.

REAR BRAKE

REAR DERAILLEUR
keeps the chain tensed.

50%
of the world's bicycles are in China.

FRAME
is composed of metallic tubes welded together.

PEDALS
act as levers, making the chain wheel rotate.

CHAIN WHEEL

History

1769 The first bicycle did not have pedals; it was propelled by the feet.

1818 Karl von Drais de Sauerbrun invented the *draisienne*, which had greater separation between the wheels, the handlebars, and the seat.

1865 Pierre Lallement added pedals connected to the front wheel, which was larger than the rear one.

1867 Clément Ader introduced the metallic frame.

1885 James Starley invented the chain-driven safety bicycle with wheels of the same diameter.

1896 Bicycles were given their current shape. The derailleur was patented.

1950 The three-speed English bicycle was introduced along with some other novel designs.

Today New materials, such as acrylic, stainless steel, and carbon fiber, have come into general use.

Boats and Ships

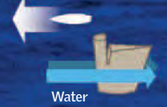
One of the first means of transportation invented, boats made it possible for people to overcome the obstacles posed by water. Although boats and larger vessels called ships have undergone many technological advances, they all depend upon the flotation principle discovered by Archimedes. Boats and ships are commonly used in trade, recreation, and military operations.

Freighters

are used to transport dry products. The model shown was first built in the 1970s, and it is still used today, though with many technological improvements.

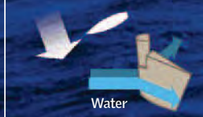
Helm
acts as a steering wheel. When it is turned, the ship changes direction.

STRAIGHT RUDDER



The ship moves straight ahead.

LEFT RUDDER



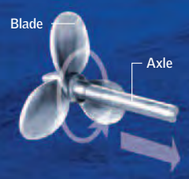
The ship turns left.

RIGHT RUDDER

The ship turns right.

Propeller (screw)

1. Driven by the engines, the propeller turns.
2. The water is pushed backward.
3. The force of reaction pushes the ship forward.



BRIDGE
The ship and all onboard activities are directed from here.

DECK CRANES
Each is controlled by an operator from a cabin.

HULL
Hollow structure made of welded steel sheets, its interior is divided into floors or decks.

WHY IT FLOATS

The steel hull is denser than the water, but because it has air in its interior, it floats.

The water pushes the boat upward.

Flag indicating the ship's country of origin

Awning

Lifeboat

STACK
bears the flag of the naval company.

LOADING HATCHES
This boat is a mixed freighter because it can store merchandise in the hold as well as in containers.

Ship's flag

Folded deck cranes

Hatch cover

WINDLASS
is used to drop and raise the anchor.

Forecastle

Handrail

MACHINERY ROOM
has the diesel engines that provide the power to propel the ship.

DOUBLE HULL
is where the fuel tanks, drinkable water, and ballast tanks are located.

Main deck

Lower deck

Orlop deck

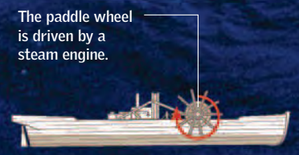
HOLD

ANCHOR

WATERLINE

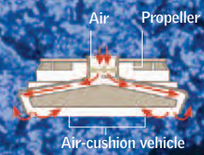
The History of Boats and Ships

SAILING SHIPS. 15TH CENTURY. The wind was the first propulsive force used. Sailing ships were widely used for journeys of exploration.



STERNWHEELERS. Beginning of the 19th century. Oldest ship propelled by an engine. The blades of the paddle wheel, acting like oars, cause the boat to move.

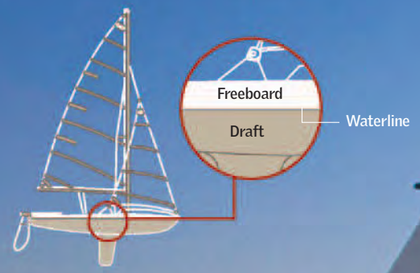
WITH A PROPELLER. Since 1830. The invention of the propeller, or screw, allowed, at a small expense of energy, the transportation of extremely heavy loads at higher speeds.



HOVERCRAFT. Since 1960. It uses propellers that produce an air cushion below the boat. Some ferries use this flotation system.

Sailboats

Very early in history, human beings used wind to carry their vessels along, covering long distances on water. This was necessary for trade and conquest, because it permitted, at much less effort than would otherwise have been necessary, the transportation of large quantities of merchandise and troops. Except for a few zones in the Indian Ocean, sailboats are now generally used for sport and recreation. The invention of triangular and trapezoidal sails that not only harness wind power but also exploit other physical phenomenon made boats easier to maneuver.



TELLTALE
Attached to the shroud and stay, it is used to indicate the direction of the wind.

MAINSAIL

CROSSTREE

SHROUDS
Usually made of steel, they keep the mast upright from the sides.

MAST

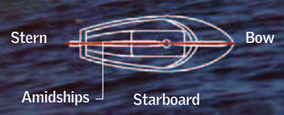
BOOM

TILLER

CABIN

DECK

SPADE RUDDER



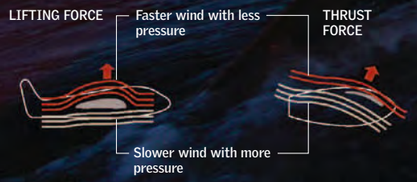
TYPES OF RIGGING
The mast, boom, forestays, and shrouds are together called rigging.

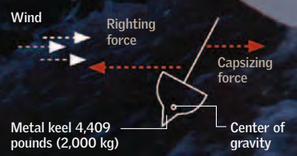
SPORTS SAILBOATS

CLIPPER

AERODYNAMIC PRINCIPLE

Sailboats use the same aerodynamic principle that enables a bird or an airplane to fly.

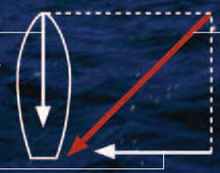




STABILITY
The weight of the keel counteracts the tilting produced by the wind.

THE WIND

propels sailboats. Sailors distinguish between three types of wind.

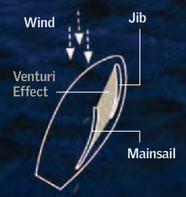


RELATIVE
is generated as the sailboat moves. This wind goes from the bow to the stern.

APPARENT
is the disparity between the relative and real winds.

REAL
is what we commonly call wind.

VENTURI EFFECT
is produced in the so-called "funnel," where the wind gains speed as the space between the sails diminishes.



COURSES

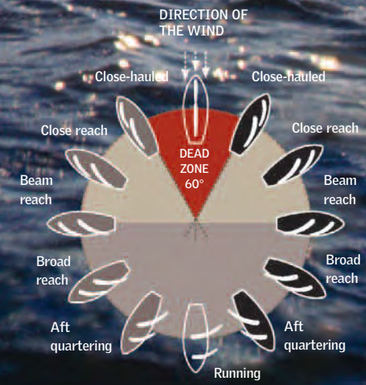
It is possible to sail in all directions except against the wind.

TO STARBOARD

TO PORT

The Venturi effect is produced. The shape of the sails is important.

The force of the thrust causes the sailboat to move. The surface of the sail is important.



Balloons

The use of balloons constitutes the first successful application of a flight technique developed by humans. Although the first recorded balloon flight was carried out by the Montgolfier brothers, the Chinese used unmanned balloons for military communication in the 2nd century AD. Because balloons are carried along by the wind, the pilot has a difficult time following an exact course or returning to the place of origin. Forgotten by the beginning of the 20th century, balloons have experienced a revival since the 1960s and are now used for sport and recreation.

WHY THEY FLY

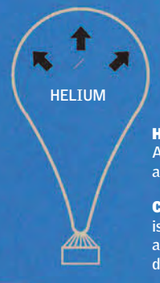
Thermal differences enable balloons to fly. Certain gases and hot air are lighter than atmospheric air.

PRESSURE, WEIGHT, AND HEIGHT
The gases are located at different heights.

Lower weight and higher pressure: greater height

Higher weight and lower pressure: lower height

GAS BALLOONS are mostly used in unmanned meteorological missions. They are usually filled with hydrogen or helium, both light gases.



HOT-AIR BALLOONS
As the air heats up, it expands and becomes less dense.

Cold air is heavier and tends to descend.

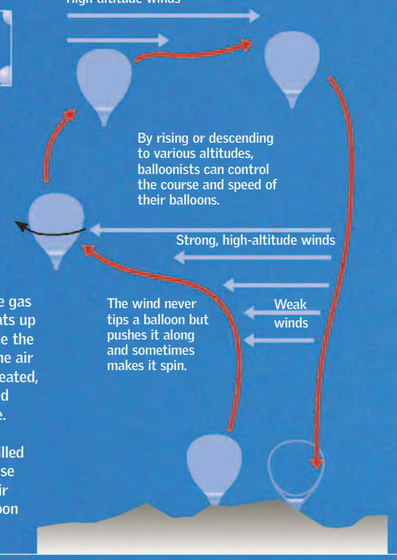
Hot air is lighter and rises.

A propane gas burner heats up the air inside the balloon. As the air molecules are heated, the air expands and becomes less dense.

When the balloon is filled with air that is less dense than the atmospheric air surrounding it, the balloon rises.

MANEUVERING IN THE AIR

Only the upward and downward movements of balloons can be controlled. To move horizontally, balloons use wind and particular air currents.

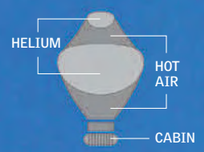


ROZIER BALLOONS

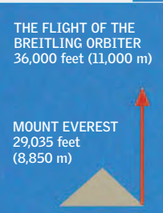
are a combination of helium and hot-air balloons.

The balloonist can change altitude by controlling air temperature.

It also allows for long trips at high altitudes.



BREITLING ORBITER 3
In 1999, Brian Jones (Britain) and Bertrand Piccard (Switzerland) flew nonstop around the world in this Rozier balloon.
The trip lasted about 19 days and 22 hours, during which the balloon was kept at an altitude that would have been too high for hot-air balloons.



Components

CONTROL FLAP
In big balloons, it is used to control the altitude.

SHUT

While it is shut, the hot air stays inside the balloon, where it maintains its lighter density, causing the balloon to ascend.

OPEN

When the valve is open, some hot air escapes, lowering the density of the air inside the balloon and causing the craft to descend.

To land, the balloon must be nearly deflated.

Dirigibles

Because of the difficulty inherent in steering a balloon, several methods of navigation, including wings and oars, were attempted. All these methods were unsuccessful until Henri Giffard added an engine to a balloon, turning it into a dirigible. However, it was Ferdinand von Zeppelin who in 1900 gave dirigibles their rigid structure and definitive shape. Dirigibles were then used to transport passengers, but now they are used almost exclusively for advertising. Many companies are considering using them to transport cargo, because dirigibles travel much faster than boats or trucks and can lift and carry up to 500 tons.

The Hindenburg

was the largest dirigible (number 108) to leave the Zeppelin production lines. In 1937, as the Hindenburg was practicing landing maneuvers, it burst into flames. Since then, dirigibles have not been used to transport passengers commercially.

Builder	**Zeppelin Shipyard**
Speed	**84 miles per hour (135 km/h)**
Capacity	**70 passengers**
Crew	**15 people**

FERDINAND VON ZEPPELIN
German aeronaut.
He had been dreaming of flying his own dirigible since 1873 but did not manage to do so until 1900. Ten years later, his airships started to transport passengers commercially.

656,000 cubic feet (200,000 cu m)
was the volume of gas contained in 16 compartments.

Over time, hydrogen, an inflammable gas, was replaced by helium, which is nonflammable.

THE STRUCTURE
Made of aluminum, it was rigid and covered by a thick cotton fabric.

RUDDER

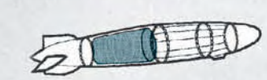
ENGINES
They had four diesel engines.

THE DECK
had two floors. It included passenger cabins, a restaurant, a lounge, a reading room, a bar, and a smoking lounge.

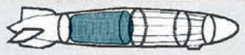
THE GONDOLA
Only crew members could enter it. The movements of the dirigible were controlled from here.

How Dirigibles Fly

WORKING PRINCIPLE
They were lifted by helium or hydrogen. These gases, being less dense than air in the lower atmosphere, caused the airship to float upward to less dense regions.



1 The gas chambers were filled up with hydrogen, and the dirigible began to rise



2 Propellers driven by diesel engines were used for horizontal movement.

3 Dirigibles had lateral fins that, when tilted downward, caused them to descend.

Airplanes

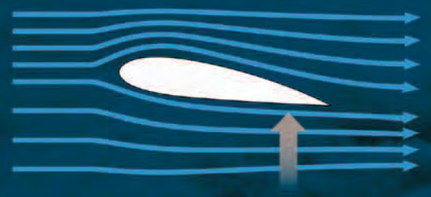
Within a century, airplanes have not only fulfilled humanity's ancient wish to fly but also have become a means of transportation used by many people and can quickly cover great distances. Even though the earliest models—made of wood, fabric, and steel—have evolved into huge jets capable of carrying hundreds of passengers over oceans as well as into supersonic military aircraft, all planes are governed by the same physical laws.

Mach

is a unit equivalent to the speed of sound. This speed depends on the temperature and other factors, but one Mach is generally considered to be 761 miles per hour (1,225 km/h).

Held Up by the Air

The upper side of an airplane's wing is curved, but the lower side is straight. This design makes the air flowing above the wing travel farther than the air below, thereby increasing its speed. As a result, the pressure of the air above decreases, and the wing is supported in part by the pressure of the air below it. If the flow of air is interrupted or is inadequate, the airplane loses lift and can stall.



Propulsion

In order to fly, airplanes must be constantly propelled forward. The most efficient system of aerial propulsion uses the expansive force of hot gases created by burning compressed air.

1. The air enters the engine and passes through a compressor, increasing its pressure.
2. The newly compressed air is mixed with fuel and burned. Its temperature increases to about 1,300° F (700° C), creating high-pressure gases that escape through the exhaust nozzles.
3. As the hot gases escape, pushing the aircraft forward, they turn turbines that power the compressor and, in some engines, the turbofans, thereby restarting the cycle.
4. The gases escape from the turbine at high speed and push the aircraft forward.

In Flight

Once airborne, a pilot controls an airplane's direction and altitude with movable surfaces controlled from the cockpit.

RUDDER

is controlled with pedals; it turns the nose of the airplane to the right or the left. The rudder usually works in coordination with the ailerons.

ELEVATOR

lifts or lowers the airplane's nose, causing the aircraft to change altitude.

FLAPS

are extendible panels used during takeoff and landing. When they extend, they increase the surface area of the wings, thereby increasing the amount of lift generated and enabling the aircraft to either takeoff or fly at even lower speeds.

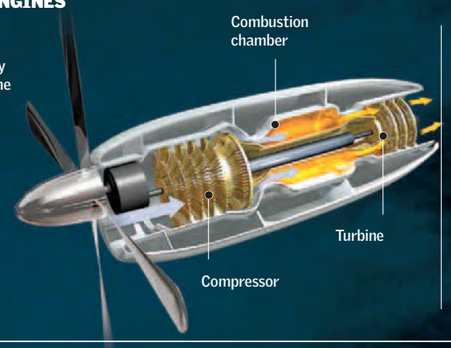
AILERONS

cause the airplane to roll during flight. They are movable panels that rotate the plane on its long axis, allowing the plane to bank into a turn. The ailerons are activated by the control wheel or stick.

SUBSONIC ENGINES

Turboprop

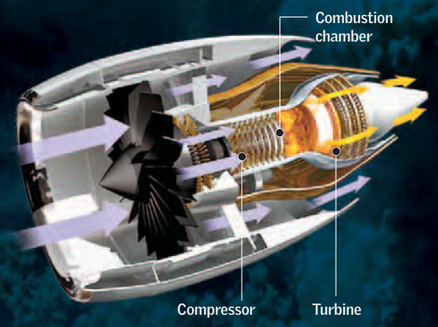
Part of the energy from the jet engine is used to turn a propeller, which provides propulsion.



Turbofan

Any excess air that enters the engine flows on both sides of the turbine without burning, thus making the engine quieter, more efficient, and more economical.

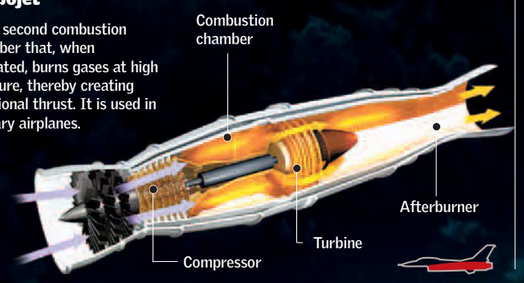
The blades draw in air



SUPERSONIC ENGINES

Turbojet

has a second combustion chamber that, when activated, burns gases at high pressure, thereby creating additional thrust. It is used in military airplanes.



HYPERSONIC ENGINES

Scramjets

are a type of experimental engine designed to operate at and above Mach 6. The air goes into the engine with such force that the aircraft requires neither turbines nor compressors but only two burners.

Helicopters

Compared to airplanes, helicopters are not only a much more complex means of transportation, but they are also accompanied by higher manufacturing, operational, and maintenance expenses. They are slower and have shorter range; they also possess lower load-bearing capacities than fixed-wing aircrafts, but all these disadvantages are offset by their great maneuverability. Helicopters can hover, remaining motionless in the air, and they can even rotate in place. They can also take off and land vertically using any reasonably large, level spot that is twice as large as the space the helicopter occupies.

Attack
AH-64
Apache

Passenger
Sikorsky S-61

Tiltrotors
V-22 Osprey

Load-bearing
Sikorsky Sky Crane

Futuristic
Sikorsky RAH-66. Comanche, almost undetectable by radars

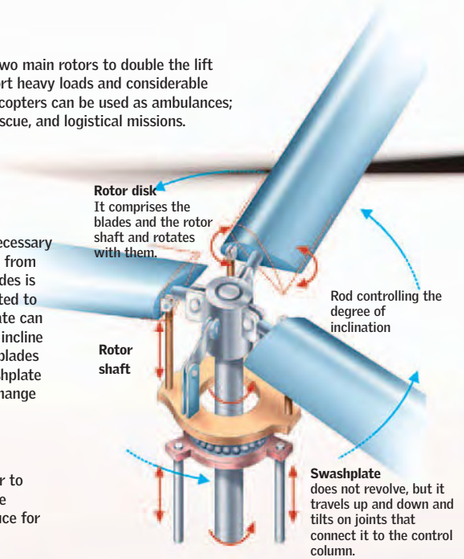
Twin Rotors

Most large helicopters use two main rotors to double the lift generated. They can transport heavy loads and considerable numbers of passengers. These helicopters can be used as ambulances; they can also be used in search, rescue, and logistical missions.

How It Flies

THE ROTOR
has blades that generate the lift necessary for the helicopter to rise and move from place to place. The pitch of the blades is controlled by a swashplate connected to two control columns. The swashplate can move upward, downward, or at an incline between the columns, holding the blades at various levels of pitch. The swashplate also moves the control axes that change the pitch of the entire rotor.

THE BLADES
have an aerodynamic profile similar to that of airplanes. Their pitch can be changed to vary the lift they produce for different types of flight.



HOVERING
The rotor blades are not pitched relative to the rotor shaft. This creates a lift equal to the weight of the machine and causes the helicopter to remain suspended in the air, moving neither forward nor backward.

VERTICAL FLIGHT
When the swashplate is raised, the pitch of each blade increases, which generates more lift and causes the helicopter to ascend. When descending, the swashplate is lowered, causing each blade to decrease pitch and generate less lift.

FORWARD
When the swashplate moves forward, the rotor disk tilts forward, increasing the lift generated by the back of the rotor to push the helicopter forward.

BACKWARD
When the swashplate is moved backward, the rotor disk tilts backward, increasing the lift generated by the front of the rotor to push the helicopter backward.

TAIL ROTOR
prevents the machine from rotating around itself.

CH-47 Chinook

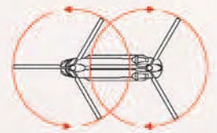
Its history started in the 1950s, when the American army developed it as a means of transportation for troops and crews. Its engines, design, and internal systems have continually improved.

Type	Tandom-rotor transport
Crew	2 pilots + 1 mechanic
Range with maximum load	621 miles (300 km)
Speed at sea level	186 miles per hour (300 km/h)
Maximum altitude	11,480 feet (3,500 m)
Engine	Two 3,750 HP turbo engines
Empty weight	21,460 pounds (9,736 kg)
Maximum weight	50,270 pounds (22,800 kg)

Tandem Rotors

The two superimposed rotors are staggered so that as they rotate their blades are at different levels and do not collide.

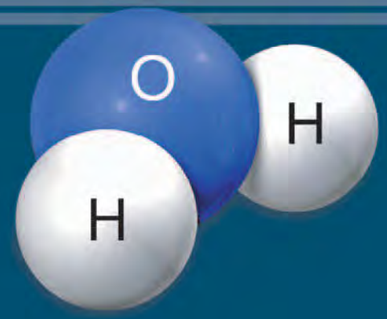
This model does not require a tail rotor, because it has two main rotors that rotate in opposite directions, each canceling the torque produced by the other.



TO ROTATE
The rudder pedals change the rotor's pitch, inclining one to the left and the other to the right or vice versa.

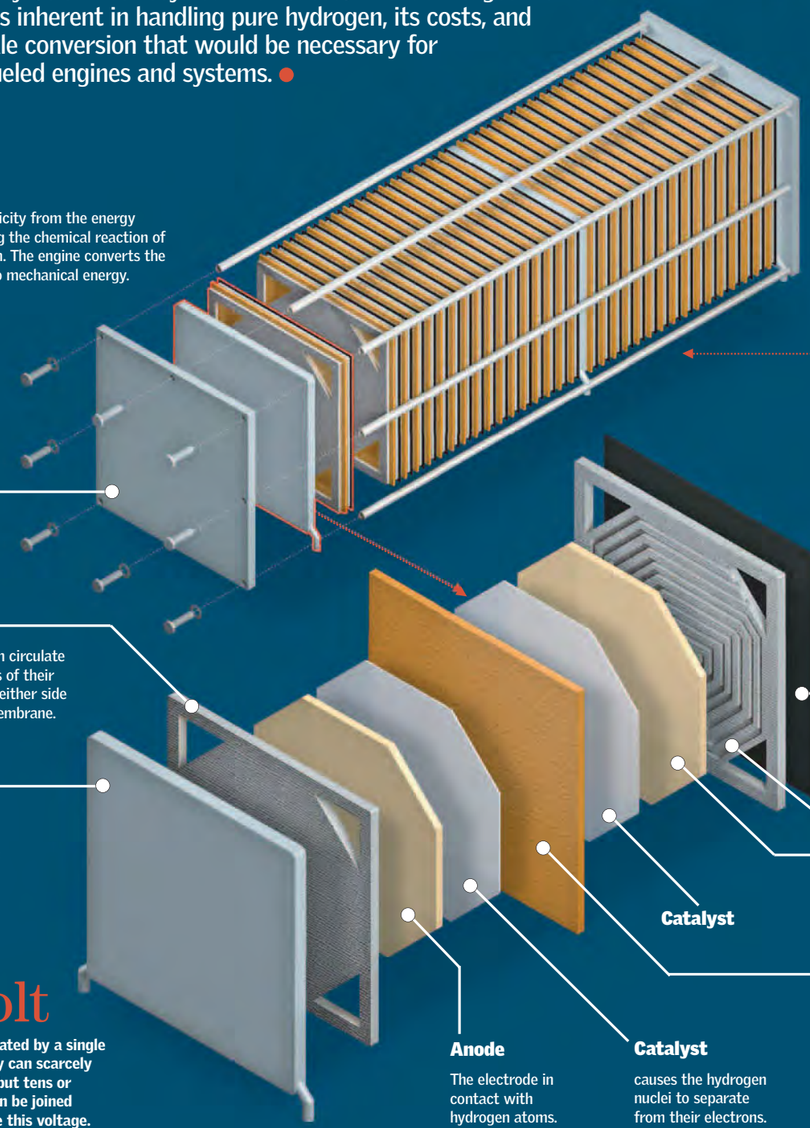
Hydrogen

Some people consider hydrogen the energy source of the future and predict that in the short term it will gain widespread use in place of fossil fuels. The hydrogen is combined with oxygen to release energy to generate electricity. Among the advantages of hydrogen-based energy are its very low pollution level (the byproduct of the reaction is water vapor) and its inexhaustibility (it can be recycled and reused). Disadvantages include the complications inherent in handling pure hydrogen, its costs, and the wide-scale conversion that would be necessary for petroleum-fueled engines and systems.



Fuel Cells

produce electricity from the energy released during the chemical reaction of hydrogen and oxygen. The engine converts the electrical energy into mechanical energy.



Fuel-cell pack

Flow plate

Hydrogen and oxygen circulate through the channels of their respective plates on either side of the electrolytic membrane.

Cooling cell

The cooling cell should be refrigerated because the reaction produced in the cell generates heat.

0.7 volt

is the voltage generated by a single fuel cell. This energy can scarcely light one lightbulb, but tens or hundreds of cells can be joined together to increase this voltage.

Anode

The electrode in contact with hydrogen atoms.

Catalyst

causes the hydrogen nuclei to separate from their electrons.

Separator

Flow plate

Cathode

is the electrode in contact with the oxygen atoms and the place where water vapor forms.

Electrolyte

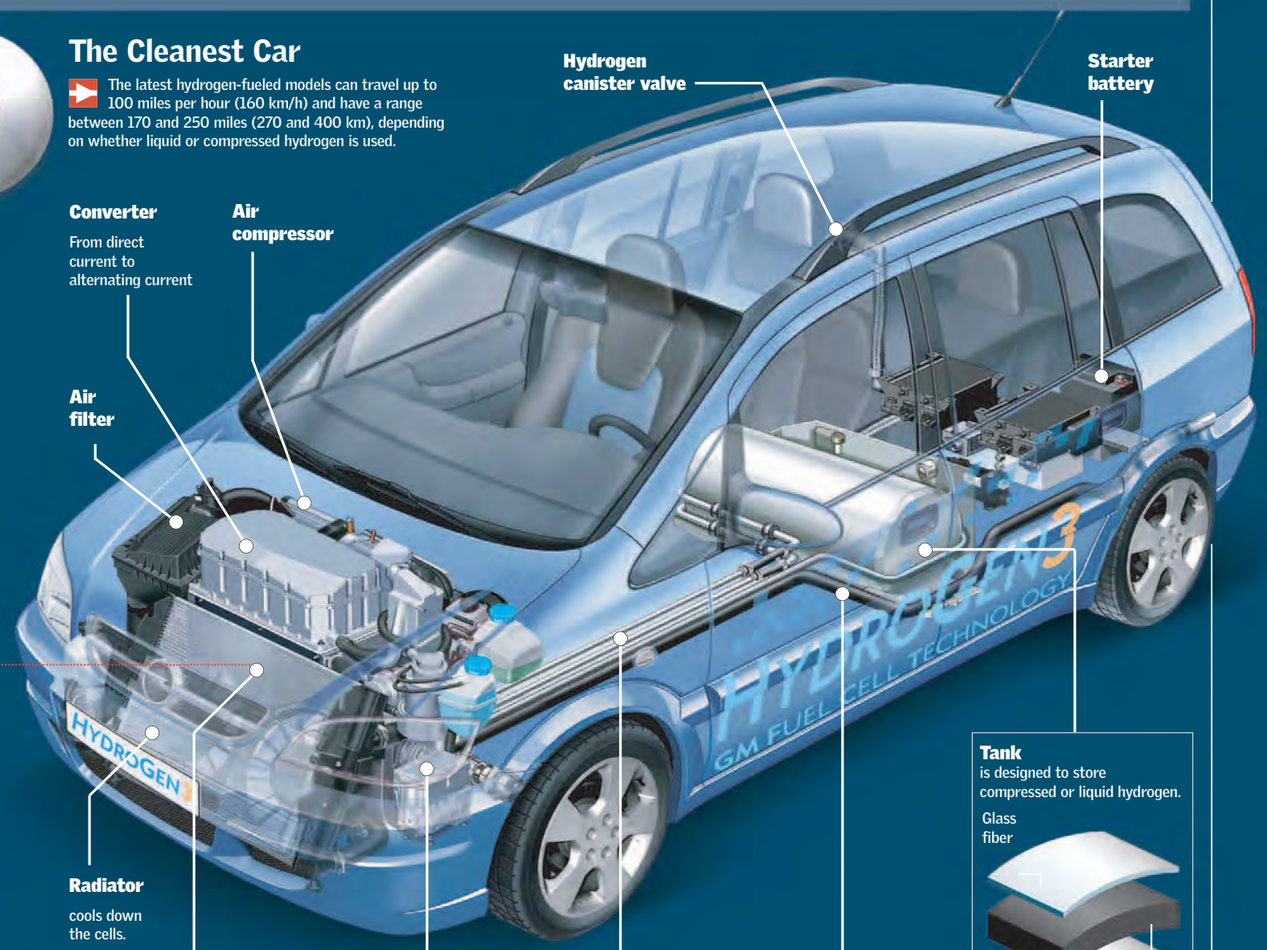
is a cell through which the hydrogen nuclei pass before reaching the cathode. It does not allow electrons, which flow through the external circuit (electricity), to pass.

200

is the average number of hydrogen cells a car engine needs.

The Cleanest Car

The latest hydrogen-fueled models can travel up to 100 miles per hour (160 km/h) and have a range between 170 and 250 miles (270 and 400 km), depending on whether liquid or compressed hydrogen is used.



Hydrogen canister valve

Starter battery

Converter

From direct current to alternating current

Air compressor

Air filter

Radiator

cools down the cells.

Fuel cells

use hydrogen and oxygen to generate electricity.

Electric engine

causes the car wheels to move.

Fuel pipes

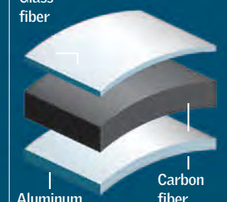
carry hydrogen from the tank to the cells.

Exhaust pipe

releases the water vapor produced by the process.

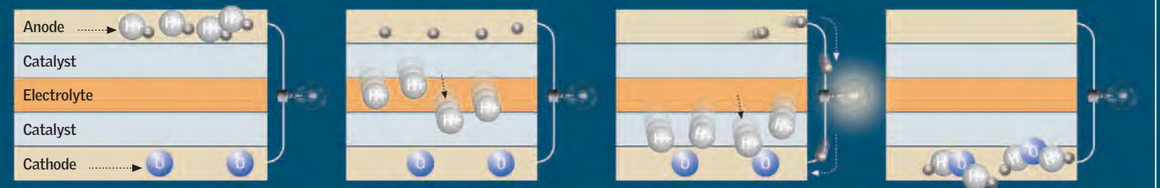
Tank

is designed to store compressed or liquid hydrogen.



How a Fuel Cell Works

The fuel cell produces electricity from the energy released when oxygen and hydrogen join to form water.



1 Hydrogen collects at the anode and oxygen at the cathode. The catalyst separates the hydrogen electrons from their nuclei.

2 Hydrogen nuclei cross the electrolytic layer without their electrons.

3 Electrons, which cannot cross the electrolytic layer, flow through the circuit until they reach the cathode, thereby producing electric current.

4 The byproducts of the process are water and heat. The reaction continues as long as fuel is supplied.

Glossary

Acid

An acid is any chemical compound that, dissolved in water, produces a solution with a pH lower than 7.

Aerodynamics

Branch of fluid mechanics that studies interactions between solid bodies in motion through a fluid surrounding them. In solving an aerodynamic problem, it is necessary to calculate properties of the fluid-such as speed, direction, pressure, density, and temperature-in relation to the position of the object through time.

Aerostatic Balloon

A flying device with a gondola for passengers attached to an envelope of lightweight, impermeable material. This envelope assumes a roughly spherical shape and is filled with gas of lower density than air; this situation creates a lift strong enough to overcome its weight.

Alkaline

Low-density, colored, soft metals that react easily with halogens to form ionic salts, as well as with water to form strong hydroxide bases. All have just one electron in their valence shell, which they tend to lose, forming singly charged ions.

Allotropy

Property certain chemical elements possess that enables them to be classified under different molecular structures or according to different physical properties. For example, oxygen can either exist as molecular oxygen (O_2) or ozone (O_3). Other examples are phosphorus, which can either occur as white or red phosphorous (P_4), or carbon, which can occur as either graphite or diamond. For an element to be defined as an allotrope, its different molecular structures must exist within the same physical state.

Alternator

Machine that transforms mechanical energy into electrical energy by using induction to generate an alternating current. Alternators are based on the principle that in a conductor subjected to a variable magnetic field, an induced voltage will be created, voltage whose polarity depends on the direction of the field and whose value depends on the flux crossing it. An alternator has two fundamental parts—the inductor, which creates the magnetic field, and the conductor, which passes through the lines of force of the field.

Ampere

Is the measure of the intensity of an electrical current. It is a basic unit of the International System of Units. The ampere is a constant current which—if maintained between two parallel conductors of infinite length but negligible circular cross section and placed three feet (1 m) apart in a vacuum—would produce a force equivalent to 2×10^{-7} newtons per meter of length. It is represented by the symbol A.

Anode

Positive electrode in an electrolytic cell, toward which the negative ions, or anions, move inside the electrolyte. In the case of thermionic valves, electric sources, batteries, and so on, the anode is the electrode or terminal with greater potential.

Atomic Bomb

Fission weapon whose great destructive power comes from the release of high-energy neutrons.

Baryon

Baryon is a hadron formed by three quarks that are held together by a strong nuclear interaction. The proton and neutron belong to this group.

Base

Substance that, in an aqueous solution, donates OH^- ions. Bases and acids are diametrically opposed. The generalized concept of pH is used for both acids and bases.

Bond

Union between atoms that form a compound or the force that keeps two chemical entities together.

Cathode

Negative electrode of an electrolytic cell, toward which the positive ions, or cations, move.

Coal

Combustible, black mineral of organic origin. It tends to be located under a layer of slate and over a layer of sand. It is believed that most coal was formed during the Carboniferous Era (280 to 345 million years ago).

Coil

Variable number of loops of an electrically conductive material wound around an empty, prismatic, or cylindrical core.

Connecting Rod

Part connected at one end to a piston, which moves in a straight line, and at the other end to a crankshaft, crank, or wheel to transform a linear reciprocating motion into rotational motion. Connecting rods are basic elements of today's internal combustion engines.

Convection

One of the three forms of heat transfer, it is produced by mass transfer between regions of disparate temperatures. Convection takes place only in fluids. When a fluid is heated, it becomes less dense and rises. As it rises it is displaced by lower-temperature fluid that, in turn, is heated, thus repeating the cycle.

Coulomb

Amount of charge that one ampere carries in one second. A coulomb is 6.28×10^{18} times the charge of an electron.

Crankshaft

Shaft that contains a series of cranks to which connecting rods are attached.

Dynamics

In physics, the part of mechanics that deals with the study of the motions of bodies subjected to force.

Dynamo

Direct-current generator used to transform mechanical energy into electrical energy.

Electric Motor

Transforms electrical energy into mechanical energy, which can be direct or alternating currents (DC or AC).

Electrical Conductor

A body is considered an electrical conductor if, when placed in contact with an electrically charged body, it transmits electricity to all points of its surface.

Electricity

Phenomenon produced by particles with positive or negative charge, at rest or in motion. Also, the subdiscipline of physics that studies electrical phenomena.

Electrolytic Cell

A device using electrical current to break down bodies called electrolytes. Electrolytes can be acids, bases, or salts. The dissociation process that takes place in the electrolytic cell is called electrolysis.

Fuse

Easily meltable metal wire or plate placed in electrical assemblies to interrupt excessive current flow by melting.

Fusibility

Property, possessed by many bodies, of changing state from solid to liquid when heated.

Gamma Rays

Electromagnetic radiation that is generally produced by radioactive elements, subatomic processes (such as the annihilation of an electron-positron pair), or very violent astrophysical phenomena. Because of the great amount of energy they release, gamma rays are a type of ionizing radiation capable of penetrating deeply into matter and seriously damaging the nuclei of cells. Because of this capability, gamma rays are used mostly to sterilize medical equipment and foods.

Gears

Toothed wheels that mesh or engage with each other or with a chain, transmitting rotational motion from one to another. The most common types are the rack and pinion as well as cylindrical, conical, helical, and worm gears.

Generator

Machine that changes mechanical energy into electrical energy.

Geothermal Energy

Energy released by hot water or steam rising from underground, as in geysers.

Gravitation

The mutual attraction between two objects with mass. It is one of the four fundamental forces known in nature. The effect of gravitation on a body tends to be commonly associated with weight.

Helium

Chemical element of atomic number 2 and symbol He. It has the properties of most noble gases, being inert, odorless, colorless, and monatomic. Helium has the lowest evaporation point of all chemical elements and can be solidified only by very great pressure. In some natural gas deposits, it is found in quantities great enough to exploit and is used to fill balloons and blimps and to cool superconductors; it is also used as bottled gas in deep-sea diving.

Hydraulic Motor

Motor that produces mechanical energy by converting the energy present in a liquid.

Hydraulic Pump

Device that takes advantage of the kinetic energy of water to move part of the liquid to a higher level. It can be of two types: piston or centrifugal.

Hydrogen

Chemical element with atomic number 1 and symbol H. At room temperature, it is a colorless, odorless, and flammable gas. Hydrogen is the lightest and most abundant chemical element in the universe. For most of their lifetime, stars consist primarily of hydrogen in a plasma state. Hydrogen is present in a multitude of substances, such as water and organic compounds, and it can react with most elements.

Hydrophone

Electrical transducer of sound that is used in water or other liquid, as a microphone is used in the air. Some hydrophones can also be used as emitters. Hydrophones are used by geologists and geophysicists to monitor seismic activity.

Induction

Phenomenon that produces an electromotive force (voltage) in a medium or body exposed

to a changing magnetic field or in a medium moving in relation to a fixed magnetic field. When the body is a conductor, an induced current is produced. This phenomenon was discovered by Michael Faraday, who stated that the magnitude of the induced voltage was proportional to the variation of the magnetic field.

Internal-Combustion Engine

Engine in which the mixture of air and fuel (e.g., gasoline or natural gas) is ignited by an electrical spark from the spark plug.

Isotope

In general, each chemical element is made of several species of atoms of different mass or atomic weight. Each one of these species is called an isotope of the given element. The atoms of each isotope have the same atomic number as well as the same proton number (Z), but they have a different mass number (A). These properties indicate that each isotope has a different and characteristic number of neutrons. The word "isotope" comes from the Greek, meaning "in the same place," as all isotopes of the same element are classified in the same place on the periodic table. By convention, isotope names are composed of the element name followed by the mass number, separated by a hyphen—for example, carbon-14, uranium-238, and so on. If the relation between the number of protons and neutrons is not stable, the isotope is radioactive.

Joule

Unit of energy and work defined as the work realized by a force of 1 newton over 1 m. It is equivalent to about 0.001 Btu (British thermal unit), and it is also equal to 1 watt-second-the work done in 1 second by a potential difference of 1 volt with a current of 1 ampere.

Kinetic Energy

Energy of bodies in motion. Also called live force to differentiate it from potential energy.

Magma

Mass of molten rocks in the deepest portion of the Earth's crust caused by high pressures and temperatures and solidified through cooling. Magma can be classified into two types according to its mineral content: mafic magmas contain silicates rich in magnesium and calcium, and felsic magmas contain silicates rich in sodium and potassium.

Magnetic Declination

Name given to the variance in degrees of the magnetic North Pole from the geographic North Pole.

Natural Gas

Gas with great caloric power, made of light hydrocarbons, such as methane, ethane, propane, and butane.

Neutron

Heavy subatomic particle with no electrical charge and with slightly more mass than a proton.

Newton

Unit of force defined as the force necessary to accelerate a 2-pound (1-kg) object by 1 m/s^2. Since weight is the force exerted by gravity at the surface of the Earth, the newton is also a unit of weight. Two pounds (1 kg) is 9.81 N.

Nitroglycerin

A powerful, unstable explosive that is oily, odorless, liquid, and heavier than water. When mixed with an absorbent body, it is known as dynamite. In medicine, it is used as a vasodilator in the treatment of ischemic coronary disease, acute myocardial infarction, and congestive heart failure. It is administered orally, transdermally, sublingually, or intravenously.

Nozzle

A tubular aperture. In a jet engine, the shape of the nozzle causes the escaping exhaust gases created through combustion to produce greater thrust.

Nuclear Energy

Energy produced from nuclear reactions, such as the fission of uranium or plutonium atoms.

Nuclear Fission

Fission occurs when the atomic nucleus is divided into two or more smaller nuclei; it generates several other byproducts, such as free neutrons and photons. This process results in the emission of large quantities of energy generally in the form of gamma rays. Fission can be induced through several methods, including the bombardment of a fissile atom with another particle of appropriate energy—generally a free neutron. The particle is absorbed by the nucleus, making it unstable. The process generates much more energy than would be released in a chemical reaction. This energy is emitted in kinetic form that comes from nuclear division and other byproducts of this division. It is also emitted as gamma rays.

Polyurethane

Polyurethane is a plastic material used in the formation of many high-performance synthetic paints, such as car paints and floor stains, as well as in foams and elastic materials.

Propane

Propane is a colorless, odorless gas. It is an aliphatic hydrocarbon (alkanes). Its chemical formula is C_3H_8. Propane is mainly used as fuel. In the chemical industry, it is used during the synthesis of propylene. It is also used as a refrigerant gas and as an aerosol propellant.

Propulsion

Motion given to a body when a force acts on it. It is also the displacement of a body in a fluid, especially in the cases of self-propulsion in space.

Proton

Subatomic particle with a positive electrical charge and 1,836 times the mass of an electron. Some theories of particle physics suggest that protons can decay despite being very stable, with a half-life of at least 1,035 years. The proton and neutron together are known as nucleons, since they make up the nuclei of atoms.

Resistivity

Specific resistance of a material in opposing the flow of electrical current at a given temperature. It is the inverse of conductivity.

Shroud

In sailing, each one of the standing riggings that lends support to the top of a pole or mast and joins it to the sides or the lower masts of the boat.

Solar Cell

Photovoltaic cell that transforms solar radiation into electrical energy.

Solar Energy

Energy obtained from the Sun. It is a renewable energy source, both as a direct source of heat and as a source of light to produce electricity by using photovoltaic cells.

Thermodynamics

The branch of physics that studies energy and its transformations between its various manifestations (such as heat), as well as its capacity to do work. It is intimately related to statistical mechanics, from which numerous thermodynamic relations are derived. Thermodynamics studies physical systems at the macroscopic level, whereas statistical mechanics tends to describe them at the microscopic level.

Thermohaline Circulation

In physical oceanography, the name given to the convective circulation that globally affects the oceanic water masses. It helps transfer heat from the tropics to the poles.

Turbine

Machine that transforms the energy contained in a stream of fluid into mechanical or electrical energy.

Vacuum Pump

Compressor used to remove air and uncondensed gases from a space, thereby reducing its pressure to below atmospheric pressure.

Vibrational Motion

Periodic, oscillatory motion in which an object moves about a point of equilibrium.

Volt

The potential difference along the length of a conductor when a 1-ampere current uses 1 watt of power. It can also be defined as the potential difference existing between two points, such that 1 joule of work is necessary to move a 1 coulomb charge from one to the other.

Water Turbine

Turbine that directly takes advantage of the energy contained in moving water.

Watt

Unit of power equivalent to 1 joule per second. Expressed in electrical units, it is the power produced by a potential difference of 1 volt and an electrical current of 1 ampere.

Wave Motion

Motion where the disturbance of a point within a medium is distributed to other points within that medium with a net transfer of energy but not of matter.

Winch

Mechanical device, driven manually or electrically, used to lift and move heavy loads. It consists of a rotating roller around which a cable or rope is wound, exerting force on the load tied to the other end. In manual winches, crossed bars at the ends of the rotating cylinder permit the application of the necessary force. Winches are an integral part of nautical equipment, among other things.

Wind Energy

Energy obtained by converting the wind's kinetic energy into mechanical energy by rotating an axle to operate a machine or an electrical generator.

Zeppelin

Rigid airship with internal gas cells. It is named after its creator, Ferdinand von Zeppelin. Zeppelins were used in World War I.

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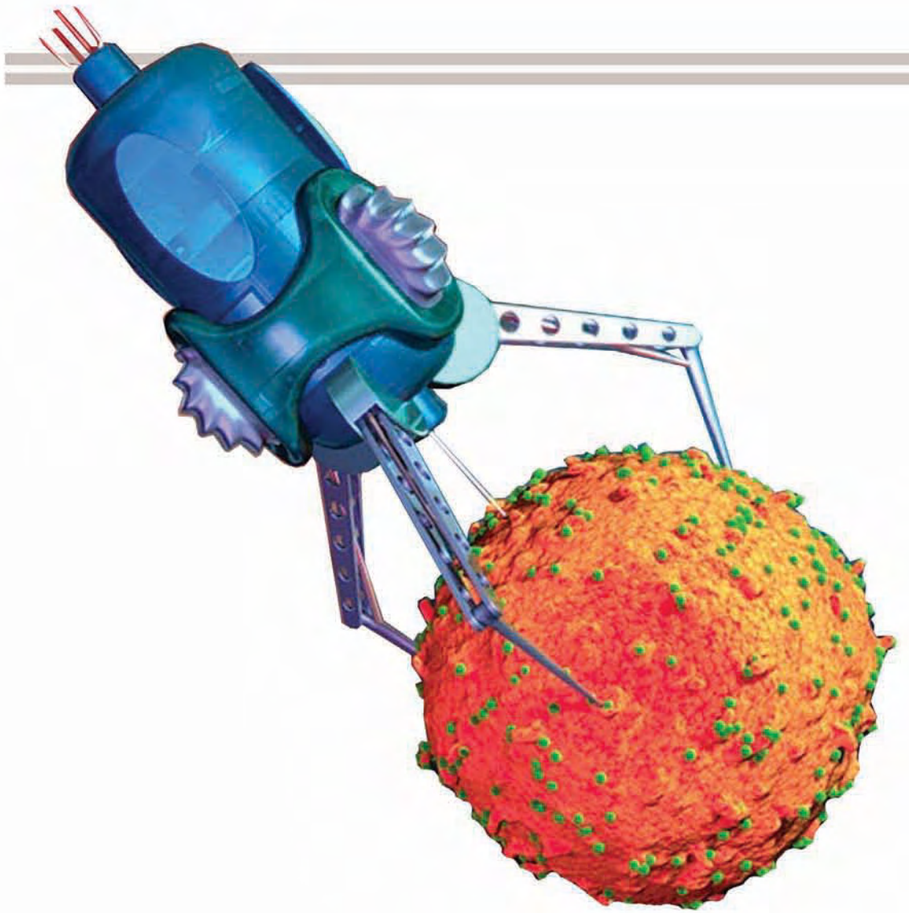

NANOROBOT
Microscopic device that is formed by arms scarcely 10 nanometers in length. In the photograph, it is shown transporting a drug through the interior of an infected cell.

An Endless Inventiveness

Many animal species use tools, and some, such as crows and apes, can even create them. But only our species has taken this ability to such an extreme that it can be said that we maintain an evolutionary symbiosis with these tools. In other words, our ability to develop complex tools increased our intelligence, allowing us to manufacture even more complex tools. This, in turn, launched a new phase in this cycle, and after several million years it finally led to the modern human, who continues to develop tools that will likely continue to transform the species. Of course, this history has not always followed a linear path. In the 9,000 years since humans discovered agriculture and cattle farming, many inventions were discovered many times and forgotten nearly as many times. Today we are surprised to learn that the Romans knew about concrete and that they had taxis and hamburger stands or that the Greeks developed the basic principles of the locomotive and the steam engine (although, oddly enough, they never combined the two to invent the railroad). We have developed the most absurd theories to explain the construction of the pyramids in Egypt or the moai of Easter Island. This winding history, with steps forward and steps backward, can be explained thus: technical inventions are a specific response to the specific needs of a given human group, and when these needs or the people who needed to meet those needs disappear or change, the inventions associated with them also disappear or change.

A few centuries ago, the creative ability of human beings took a major leap forward when tools associated with craft and empirical techniques began to complement science, thus systematizing the methods of production. This is how modern technology emerged, allowing improved preservation not just of know-how but also of the economic, social, and cultural aspects involving this know-how. Once tool making ceased to be something that was passed on from master craftsman to apprentice and became an organized set of procedures and knowledge accessible to a specialized community, the human ability to invent new tools underwent an explosion similar to the one it experienced 9,000 years earlier. Virtually overnight thousands of objects appeared (and would continue to appear) that changed our way of seeing and understanding the world—the clock, which allowed us to divide time and set a new pace for our lives; the printing press, which allowed knowledge to be spread beyond a privileged few; the refrigerator, which enriched and diversified our nutrition practices; the cinema, which opened up the possibility of dreaming while awake; the Internet, which erased borders and distances; and robotics and artificial intelligence, which led us to question our definition of being human. With the emergence of technology, you could say that our lives are surrounded by marvelous objects.

This book takes us on a journey through some of the inventions that have changed our everyday habits and our understanding of the world that surrounds us. It is not meant to provide a thorough or definitive view. The creative abilities of human beings will always make such a task incomplete. Here we look at the revolutionary technologies that mark milestones in the development of technology. We also examine inventions that have become so essential in our daily lives that it is difficult to imagine the way the world was prior to their existence. We look at technologies that have lengthened our life expectancy and improved our health. We also explore inventions that are just now beginning to show their potential and are opening up worlds that not even the most imaginative science-fiction authors could have foreseen. It is surprising to see the degree to which many of these technologies are related, like a rich tapestry of invention and creativity that make us grow as a species, expand our culture, satisfy our needs, and shape us as a society. ●

Daily-Life Applications

LIVE TV
Thanks to television we can watch events as they happen, like this girl who is watching the liftoff of Soyuz 9 in 1975.

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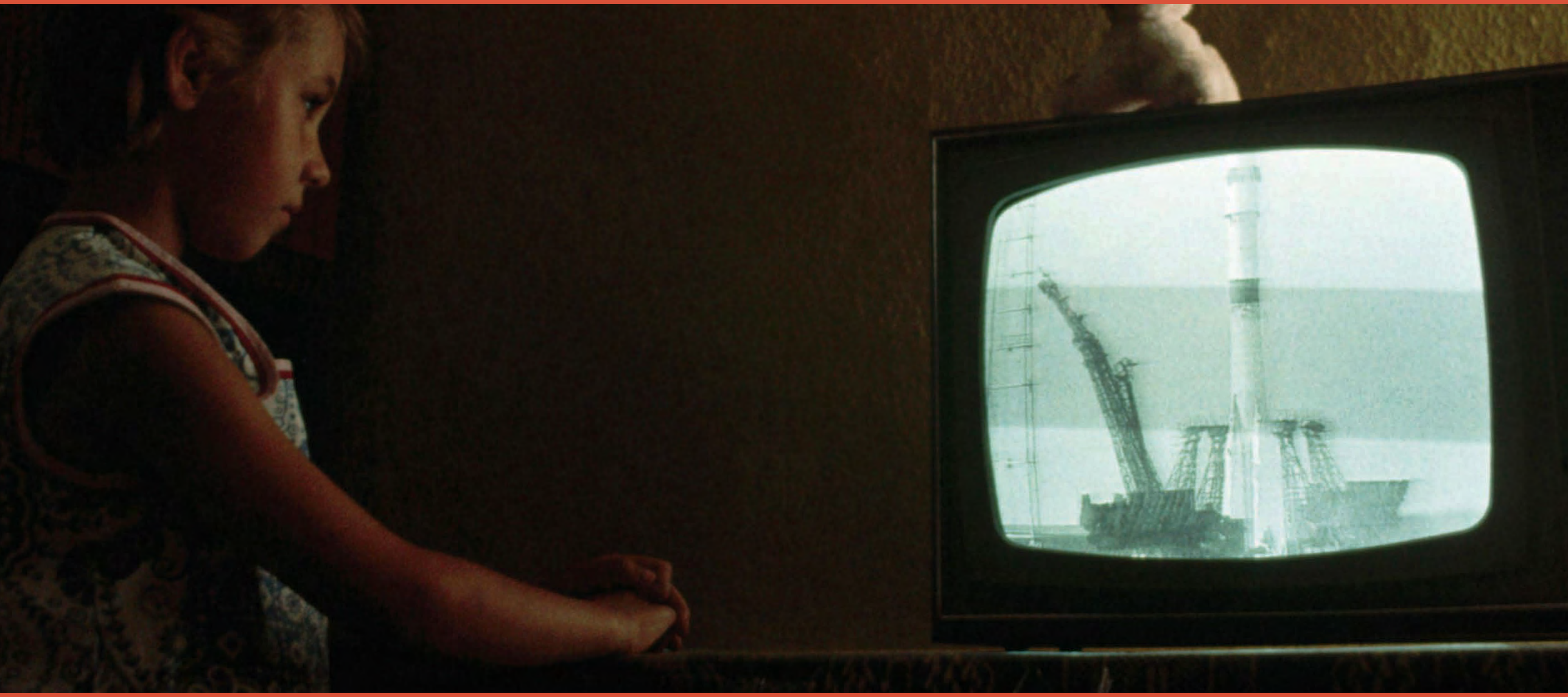


Technology has been an integral part of our daily lives for several decades now, drastically affecting us in many positive ways. Liquid crystal displays (LCD) form a part of a plethora of industrial and consumer appliances, such as automated teller machines, home appliances, television equipment, and computers. The scanner, calculator, and fax revolutionized the worlds of work and study, and photography, the DVD, and the camcorder allowed us to stop time and save unique moments forever. Our daily lives are altered by technology. We see it wherever we look; it offers us the things we have always sought: comfort, entertainment, and the tools to make our daily tasks easier. ●

The iPod

This fifth-generation, sophisticated multimedia player, introduced by Apple in 2001, currently lets users store and play up to 80 GB of music, video, and images, encoded in many formats; it also allows them to transfer information from both Mac and PC computers. The iPod can download new files from iTunes, an exchange software developed by Apple. This software serves as a complex data manager, allowing customers to purchase files from a library of more than 3 million songs and 3,000 videos. ●

Endless Entertainment

One of the most notable features of the attractively designed iPod is its ability to store high-fidelity recordings. In a size slightly larger than the palm of a person's hand, users can store up to 80 GB of data.

Music

The iPod can store more than 20,000 songs in its 80 GB version (and up to 7,000 songs in its 30 GB version).

Video

The 80 GB version can store and play more than 100 hours of video in various file formats.

Games

The iPod comes with four games, but it is possible to download a large number of games from iTunes.

Images

Stores more than 25,000 images. Plugged into a home theater system, it can display the images with musical accompaniment on a large screen.

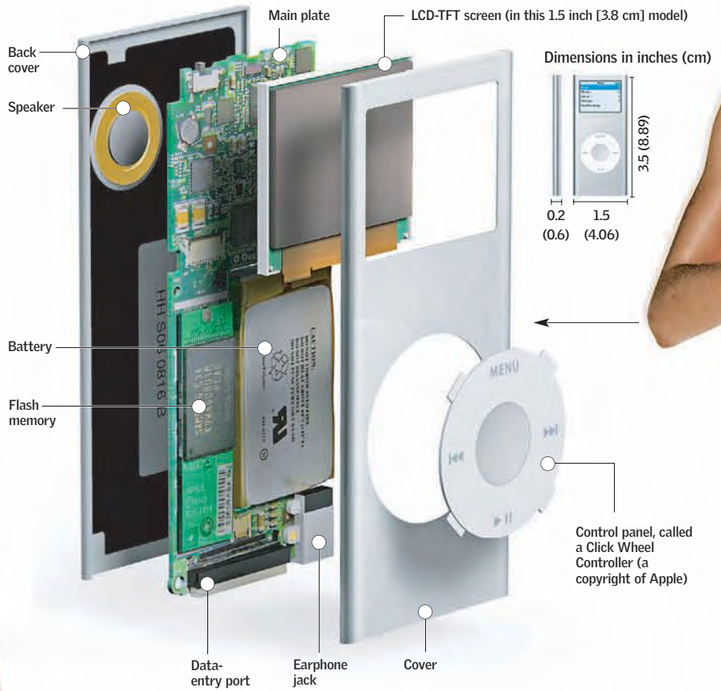
Evolution

Since its launch in 2001, the iPod has become smaller, lighter, and more efficient. It now has a color screen, and its maximum storage capacity is 16 times greater than the first model. The iPod spawned a flourishing business in accessories, and it has become a symbol of an entire generation. Today it is the most popular portable multimedia player.

2001	2004	2004	2005	2005	2005	2007
Original iPod	**Mini iPod**	**U2 iPod**	**iPod Nano**	**iPod Shuffle**	**5G iPod**	**iPod Touch**
The first version of the iPod held 5 GB of information.	Up to 6 GB capacity. Discontinued.	This model was launched in partnership with the band U2 and Universal Music Group.	The successor of the iPod mini. Smaller and lighter, with a color screen. Holds up to 8 GB.	The smallest model, it weighs only 0.5 ounce (15 g) and has no screen.	Holds up to 80 GB; 2.5-inch (6.3-cm) color screen.	A touch screen in full color with access to YouTube

Complexity in a Small Container

The interior of a 2 GB iPod Nano illustrates the complexity of this multimedia player. Chips, circuits, plates, ports, and even a thin liquid crystal display fit into a space only 3.5 x 1.5 inches (9 x 4 cm).



Contacts

Each time the iPod connects with a computer, it uses its address book and its calendar, one of its most useful applications.

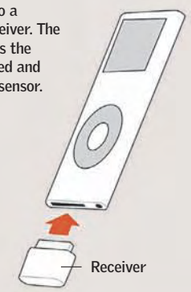
FOR SPORTS ENTHUSIASTS

The partnership between Apple and Nike resulted in an iPod that provides the athlete with preprogrammed music to accompany an exercise regimen, even as it monitors performance variables, such as pace, speed, distance covered, and calories burned.

1 A sensor is placed on the left shoe to collect data during the physical activity.

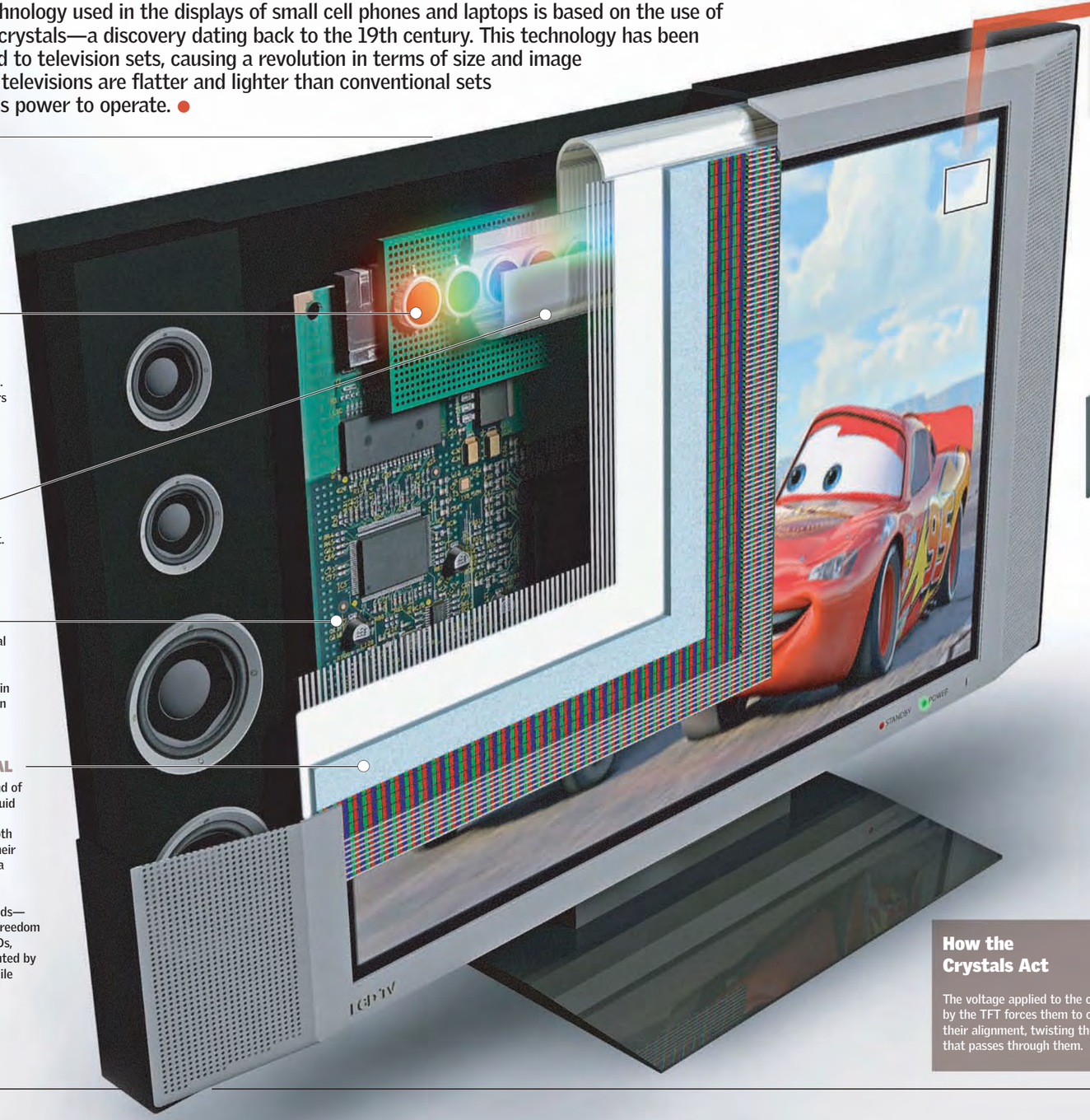
2 The iPod Nano is connected to a wireless receiver. The iPod receives the data gathered and sent by the sensor.

3 While enjoying music chosen for its beat, the user receives a performance report, which is stored in the iPod for reference.



LCDs

The technology used in the displays of small cell phones and laptops is based on the use of liquid crystals—a discovery dating back to the 19th century. This technology has been applied to television sets, causing a revolution in terms of size and image quality. LCD televisions are flatter and lighter than conventional sets and need less power to operate. ●



INSIDE THE SCREEN

LED BULBS
State-of-the-art screens use diodes, which emit red, green, and blue light. Together these colors form a powerful white light that replaces traditional fluorescent tubes.

DIFFUSER
controls brightness and softens the light.

CIRCUITS
convert the TV signal into electric instructions for the liquid crystal to use in forming the image on the screen.

LIQUID CRYSTAL
Discovered at the end of the 19th century, liquid crystals share characteristics of both solids and liquids. Their molecules can have a specific crystalline structure—which is characteristic of solids—but still have some freedom of movement. In LCDs, crystals can be oriented by electric impulses while staying in place.

THE IMAGE
is formed by hundreds of thousands of points of light called pixels. The color and intensity of each pixel is controlled by the combined brightness of the red, blue, and green subpixels.

The color of each pixel depends upon the brightness of each subpixel.

The mixture of the three subpixels at maximum brightness produces white light.

If the three subpixels are dimmed completely, the pixel becomes black.

The Path of the Light

Inside an LCD screen, white light is turned into a TV image with the help of polarizers, microscopic crystals, and color filters. Much of the process depends on technology that orients the light rays in a precise manner. From an environmental point of view, LCD screens emit almost no electromagnetic radiation, and their energy consumption can be less than 60 percent of what the cathode-ray tube of a conventional television set requires.

1 Source
sends white light, the waves of which naturally disperse in all directions.

2 First polarizer
arranges the white light in a series of vertical rays.

3 Thin-film transistor (TFT)
A thin film of crystal, covered in microscopic transistors, which acts according to the TV signal, sending instructions for crystal positioning.

Pixel

108
Size in inches of the largest LCD TV screen in the world. The screen, 7.8 feet (2.4 m) wide by 4.4 feet (1.35 m) high, has 2.07 million pixels.

Subpixels

Microtransistor

Passive crystal

Full-intensity light ray

Blocked ray

Antiglare layer

30
is the times per second that the entire process repeats itself. The speed is doubled in a high-definition TV.

4 Liquid crystal
Hundreds of thousands of microscopic crystals oriented according to the "instructions" given by the TFT, they interfere with light waves and twist them in specific directions.

5 Color filters
The white light waves twisted by the crystals are transformed into red, green, and blue waves.

6 Second polarizer
filters the light waves in a horizontal direction. The brightness of the subpixels varies depending on the direction given the light waves by the liquid crystal.

How the Crystals Act

The voltage applied to the crystals by the TFT forces them to change their alignment, twisting the light that passes through them.

Light Intensity
The crystals are made to twist the rays of light. The light's final brightness depends on how horizontal the rays are.

Blocked light
This takes place when the crystals only let vertically oriented light waves through, which are then blocked by the second horizontal polarizer.

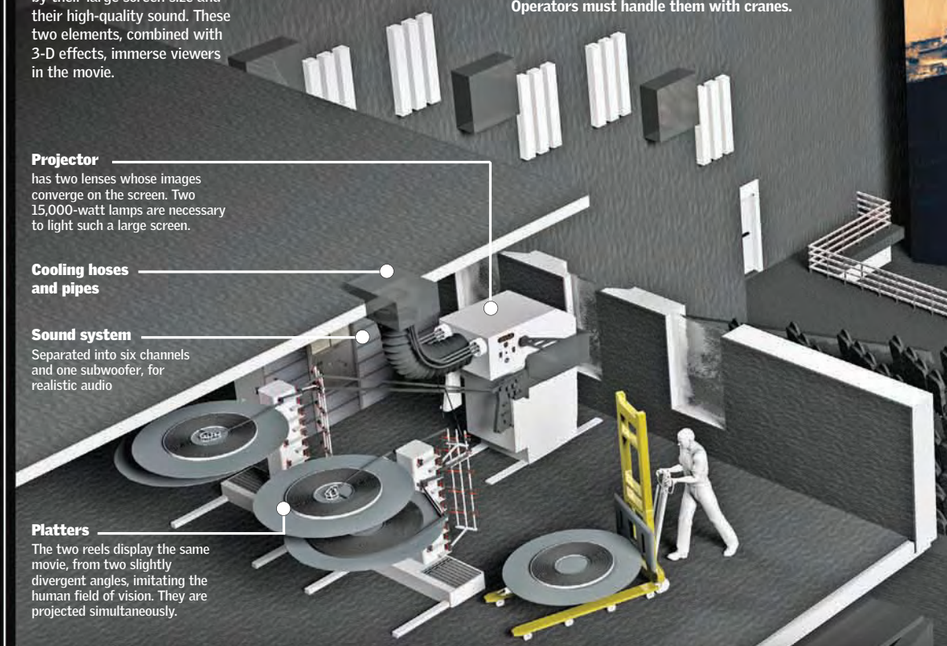
3-D Movies

The recent appearance of 3-D movie theaters with IMAX technology put the public in touch with new ideas in cinematography. The images' high resolution and large size (exceeding human peripheral vision), combined with high-quality sound and three-dimensional effects, attempt to immerse viewers within a movie. At first, only documentary films were shown in these theaters, because special filming systems were required. However, in recent years, more and more commercial films have been produced in this format.

The Theater

IMAX movie-projection rooms are characterized by their large screen size and their high-quality sound. These two elements, combined with 3-D effects, immerse viewers in the movie.

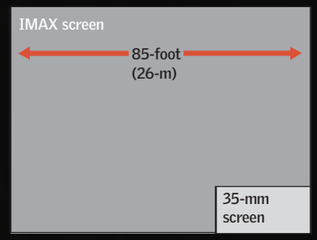
573 pounds (260 kg)
is the average weight of an IMAX film reel. Operators must handle them with cranes.



Comparison with 35-mm Movies

The greatest achievement of IMAX theater in comparison to traditional movie theaters is the size and quality of the images projected, combined with the sound system and 3-D effects.

THE SCREEN
These are the largest screens in the movie industry. They are more than 65 feet (20 m) wide, and the high-resolution projection produces excellent image quality. Because they surpass the normal range of human peripheral vision, viewers feel completely immersed in the film.

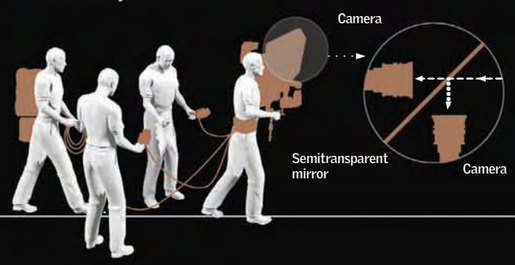


THE FILM
Each frame measures 1.9 by 2.7 inches (50 by 70 mm) and has 15 perforations. In other words, it has 10 times the surface area of the 35-mm film used in traditional projections. Each image corresponds to two frames filmed from slightly different angles, producing a 3-D effect. Unlike conventional movies, the film moves through the projector horizontally—and at much greater speed.

Filming for IMAX

To achieve 3-D effects, two cameras are used in IMAX filming. Each camera corresponds to a different eye, with the angle of separation reproducing the angle of separation between human eyes.

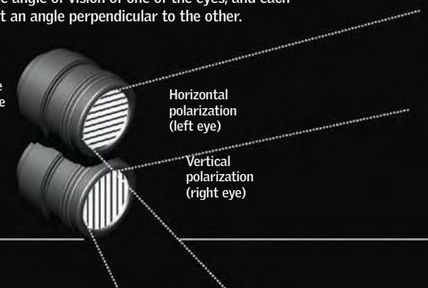
Because the two cameras cannot be placed close enough to achieve the 3-D effect, a mirror is used to resolve the problem.



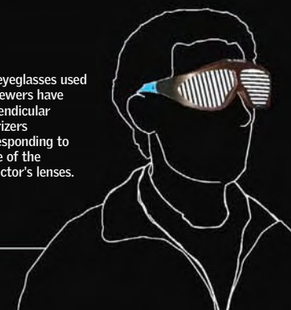
The 3-D Effect

uses two lenses to converge images on the screen. Each lens corresponds to the angle of vision of one of the eyes, and each projection is polarized at an angle perpendicular to the other.

1 Each projector lens polarizes the image at an angle perpendicular to the other.



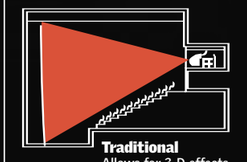
2 The eyeglasses used by viewers have perpendicular polarizers corresponding to those of the projector's lenses.



3 Thus, during the projection of the movie, the polarizers of each eye allow the corresponding image through, blocking the image intended for the other eye.

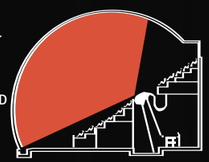
Projection Theaters

IMAX technology allows for two types of theaters: the traditional type with a large, flat screen, and dome-shaped rooms, in which the projection extends to the sides and ceiling.



Traditional
Allows for 3-D effects

Dome
The viewer feels immersed within the film. No 3-D effects.



The DVD

The storage capacity of a DVD, six times that of a traditional CD, has revolutionized the way digital data is organized and stored in the decade since its appearance in 1997. The DVD explosion resounded in the world of home movies thanks to its capability of storing entire feature films, bonus material, and subtitles (in various languages) on only one disc. The evolution of technology, however, has not stopped with DVDs. Recent years have seen the introduction of discs able to hold 12 times the data of the DVD. ●

Reading with Light

Optical discs (CDs and DVDs) are read by a laser beam to obtain information. This information is transformed into a binary electric signal that is later interpreted and converted into sounds, images, and data.

1 **Laser emitter**
generates a laser beam of a specific wavelength.

2 **Mirrors**
guide the ray by working in coordination.

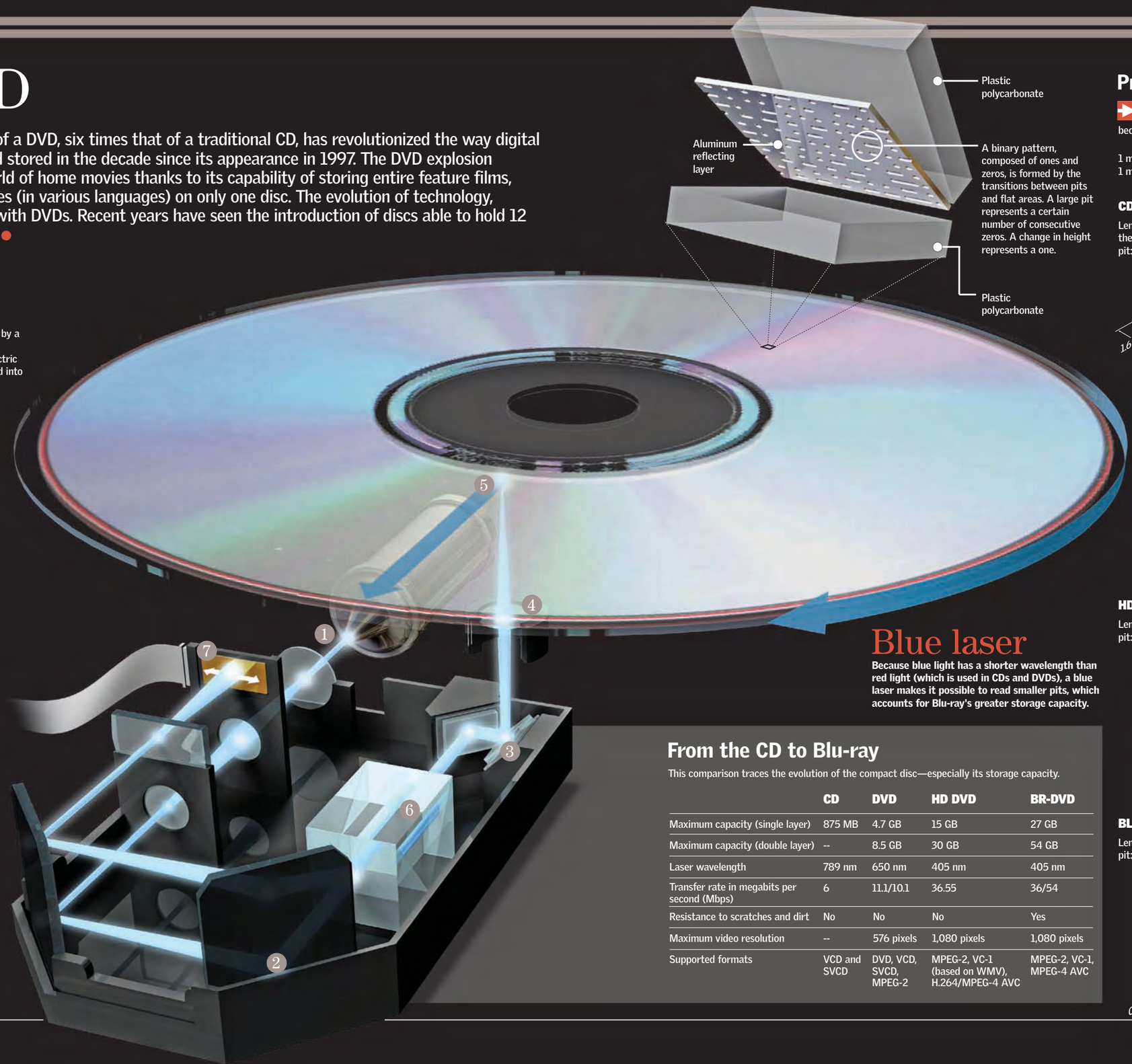
3 **Direction**
In order to read the disc, the laser beam must strike the surface of the disc perpendicularly.

4 **Lens**
focuses the laser beam before it reaches the surface of the disc.

5 **Reading**
The laser beam strikes the disc's reflective surface. The reflection varies according to the pattern of pits on the disc's surface.

6 **Prism**
changes the direction of the laser beam that reflects from the disc and contains the data read from the disc.

7 **Photodiodes**
translate the variations in the returning laser beam and convert them into a digital signal.



Blue laser

Because blue light has a shorter wavelength than red light (which is used in CDs and DVDs), a blue laser makes it possible to read smaller pits, which accounts for Blu-ray's greater storage capacity.

From the CD to Blu-ray

This comparison traces the evolution of the compact disc—especially its storage capacity.

	CD	DVD	HD DVD	BR-DVD
Maximum capacity (single layer)	875 MB	4.7 GB	15 GB	27 GB
Maximum capacity (double layer)	--	8.5 GB	30 GB	54 GB
Laser wavelength	789 nm	650 nm	405 nm	405 nm
Transfer rate in megabits per second (Mbps)	6	11.1/10.1	36.55	36/54
Resistance to scratches and dirt	No	No	No	Yes
Maximum video resolution	--	576 pixels	1,080 pixels	1,080 pixels
Supported formats	VCD and SVCD	DVD, VCD, SVCD, MPEG-2	MPEG-2, VC-1 (based on WMV), H.264/MPEG-4 AVC	MPEG-2, VC-1, MPEG-4 AVC

Profiles*

From the CD to Blu-ray, information storage has become denser, and the wavelength of the reading beams has become shorter.

1 millimeter = 1,000 micrometers (μm)
1 micrometer = 1,000 nanometers (nm)

CD
Length of the shortest pit: 0.9 μm
* Inverted view
1.2 μm
0.1 μm
1.6 μm

DVD
Length of the shortest pit: 0.4 μm
* Inverted view
0.6 μm
0.6 μm
0.74 μm

HD DVD
Length of the shortest pit: 0.204 μm
* Inverted view
0.6 μm
0.6 μm
0.4 μm

BLU-RAY DVD
Length of the shortest pit: 0.15 μm
* Inverted view
0.1 μm
1.1 μm
0.32 μm

Nintendo Wii

With the launch of Wii, Nintendo tried to cause a revolution in the world of video-game consoles. Wii, the fifth generation of Nintendo's video-game consoles and part of the seventh generation of video gaming, is the successor to Nintendo's GameCube. Wii has several features intended to help a wider audience play video games and get closer to the world of virtual reality. Among them are sophisticated wireless commands that transfer tactile effects, such as blows and vibrations; infrared sensors that detect the position of the player in a room and convey the information to the console; and separate controls for each hand. Wii was a commercial success from the moment of its launch in December 2006.

The Console

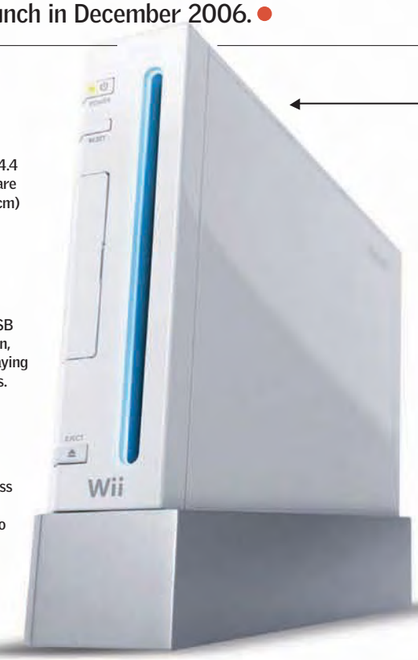
is the brain of Wii. Its slim design (a mere 1.7 inches [4.4 cm] wide) plays the games that are loaded on standard 4.7-inch (12-cm) discs, accepting both single- and double-layered discs.

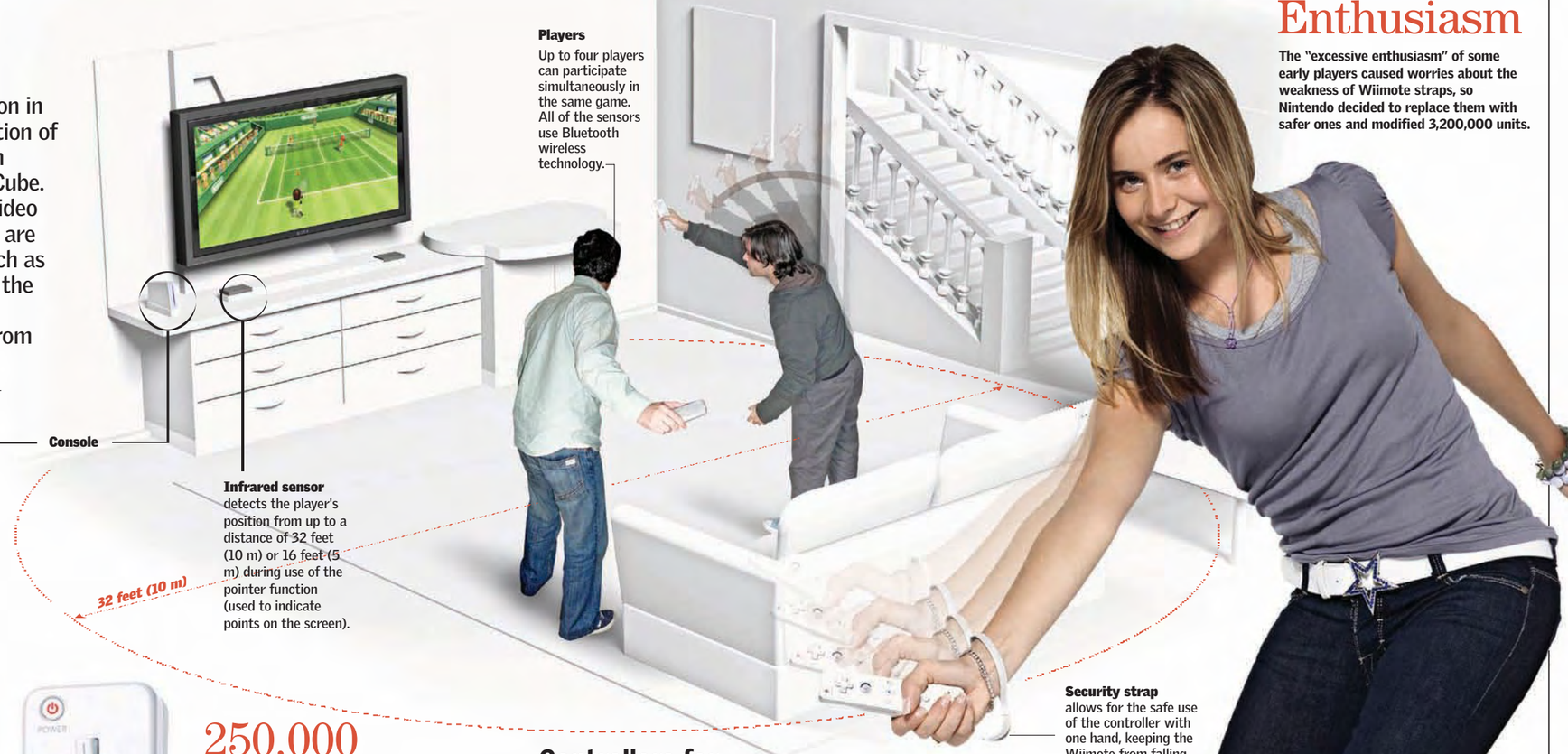
System

has an IBM PowerPC processor, ports for four controllers, two USB ports, slots for memory expansion, stereo sound, and support for playing videos on panoramic 16:9 screens.

Connectivity

The console connects with the Internet (it includes Wi-Fi wireless connection), from which it can receive updates 24 hours a day to add or upgrade features.





Enthusiasm

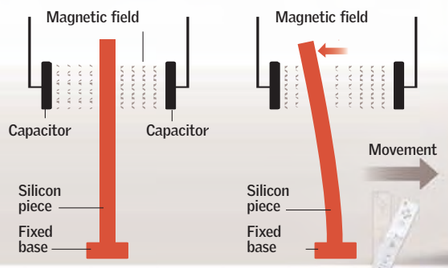
The "excessive enthusiasm" of some early players caused worries about the weakness of Wiimote straps, so Nintendo decided to replace them with safer ones and modified 3,200,000 units.

The Wiimote

The Wiimote, the Wii's remote, differs from traditional game consoles by looking more like a remote control than a videogame controller. It was developed to be useable with just one hand.

The Movement Sensor

A player's movements are detected by means of a flexible silicon bar inside the Wiimote. This bar moves within an electric field generated by capacitors. The player's movements cause the bar to change the electric field. The change is detected and transmitted to the infrared sensor, which translates it into the movements of the virtual character.



Vibrator
generates vibrations appropriate for the situation, such as when shooting a gun or hitting a ball.

Internal speaker
reproduces sounds, such as gunshots or the clash of swords.

Console buttons (holding down both buttons activates Wiimote's discovery mode, which can be used to set it up to work with a Bluetooth-enabled PC)

LED light
indicates which player is active in multiplayer games.

250,000

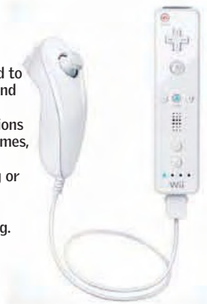
Wii consoles are manufactured daily by Nintendo. In preparation for the Wii's launch in Japan, 400,000 units were manufactured (an unprecedented quantity for a new console), all of which were sold within a few hours.

Controllers for every occasion

Port is used to add peripherals, such as the Nunchuck, which not only enhances its functions but also its traditional controller.

Nunchuck

It is connected to the Wiimote and introduces additional options for specific games, such as two-handed boxing or changing viewpoints in target shooting.



Traditional controller

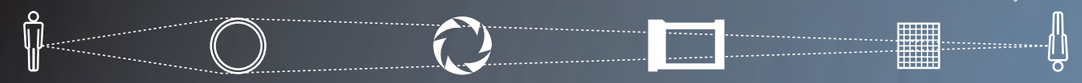
This controller is still necessary for playing with games from earlier Nintendo consoles.

The Digital Camera

The word "photography" comes from Greek words which, combined, mean "to draw with light" (from *photos*, or "light," and *graphis*, or "drawing"). Photography is the technique of recording fixed images on a light-sensitive surface. Digital cameras are based on the principles of traditional photography, but, instead of fixing images on film coated with chemical substances sensitive to light, they process the intensity of the light and store the data in digital files. Modern digital cameras generally have multiple functions and are able to record sound and video in addition to photographs.

The Digital System

1 IMAGE CAPTURE



Object

Objective
The objective focuses the image, refracting the light rays that arrive from the object so that they converge into a coherent image.

Diaphragm
It determines the amount of light that enters through the lens. This is measured in f-numbers. The greater the f-number, the smaller the opening of the diaphragm.

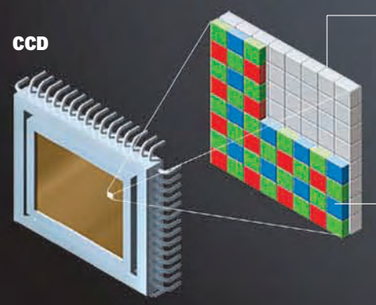
Shutter
The shutter determines the length of the exposure. It is generally measured in fractions of a second. The faster the shutter, the shorter the exposure.

CCD

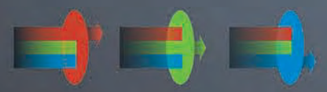
Digital image
The image appears upside down and laterally inverted.

THE SENSOR THAT REPLACES FILM

The CCD (charge-coupled device) is a group of small diodes sensitive to light (photosites), which convert photons (light) into electrons (electric charges).



Photosites
are light-sensitive cells. The amount of light shining on the photosites is directly proportional to the electric charge that is accumulated.



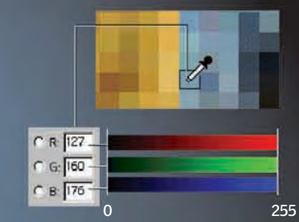
Filters
To generate a color image, a series of filters must unpack the image into discrete values of red, green, and blue (RGB).

2 Binary system processing

To convert the electric charges of the photosite (analog) to digital signals, the camera uses a converter (ADC), which assigns a binary value to each one of the charges stored in the photosite, storing them as pixels (points of color).

ADDITIVE MIXTURE

Each pixel is colored by mixing values of RGB. Varying quantities of each of these colors can reproduce almost any color of the visible spectrum.



The value of each can vary from 0 (darkness) to 255 (the greatest color intensity).

RESOLUTION

is measured in PPIs, or pixels per square inch—the number of pixels that can be captured by a digital camera. This figure indicates the size and quality of the image.

110 million
The number of digital cameras sold worldwide during 2006.

3 Compression and storage

Once the image is digitized, a microprocessor compresses the data in memory as JPG or TIFF files.

A Long Evolution

1500 — The camera obscura
Light rays reflected by an object pass through a tiny hole and are projected as an inverted image within a box. A lens concentrates the light and focuses the image. Mirrors are used to reflect the image on a flat surface, and an artist traces the projected image.

1725 — A light-sensitive substance
Experiments by the German scientist Frederick Schulze prove that light blackens silver nitrate.

1802 — The optical and chemical principles are combined.
Images are created by placing sheets directly over the light-sensitive paper and exposing them to sunlight. The images cannot be fixed.

1826 — Nicéphore Niépce
exposes a tin plate, covered with bitumen, to light for eight hours. The bitumen hardens and turns white from the exposure, producing an image. The non-hardened areas are then washed away.

1839 — The daguerreotype
The daguerreotype obtained finely detailed images on copper plates covered with silver and photosensitized with iodine. The images (single and positive) are developed with mercury vapor and fixed with saline solution.

1841 — The calotype
Invented by Talbot, this is the first positive-to-negative process. The exposures last from one to five minutes. An unlimited number of prints could be reproduced from a single negative.

1851 — Glass plates
The substitution of paper for a glass plate is perfected. The plates are sensitized with silver nitrate, which received the negative image. The exposure is only a few seconds.

1861 — In color
The Scottish physicist James Clerk Maxwell obtains the first color photograph by using light filters to produce three separate negatives.

1889 — Flexible film
The Kodak camera uses a roll of photosensitized celluloid film. The film could be used for 100 photographs using exposures of only a fraction of a second.

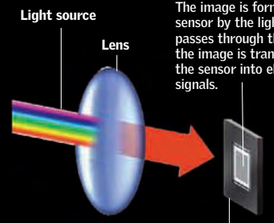
1907 — Color photograph
The Lumière brothers perfect the procedure of using glass plates covered with different colored grains to produce images formed by tiny points of primary colors.

1989 — The video photograph
Sony produces a reflex camera that records images on a magnetic disc. The images could be viewed on a television set.

Video

Created at the end of the 1950s, video was originally a technology linked to television. Before its invention, programs had to be broadcast live, with all of the inconveniences associated with such a live event. Very soon, new possibilities were found for video, and in 1965, the Korean artist Nam June Paik made the first art video. In 1968, Sony developed the first portable video camera. On the other hand, the launch of the VCR system by Philips in 1970 made viewing movies at home a part of everyday life.

1. IMAGE RECORDER
Digital cameras allow for capturing video as well as for taking pictures, using the same technology.



CCD chip
The image is formed on this sensor by the light that passes through the lens, and the image is transformed by the sensor into electric signals.

An internal program translates the light data (analog information) into the binary system (digital information).

The image will be comprised of cells called **pixels.** It can be used directly in a computer.

Several formats

Different systems and media are used for different applications, depending on the final quality desired.

HI8

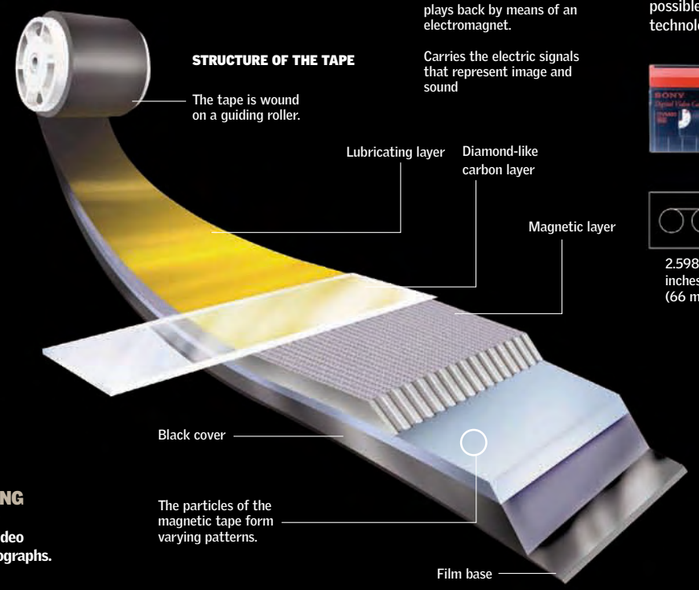
DIGITAL 8

DVD

MINI DV

FOR PROFESSIONAL USE
DV cam
Digital betacam

2. STORAGE
Data is stored as bytes. The image can be reproduced without losing image or audio quality. The level of detail is greater in digital than in analog.



25%
more quality than the analog formats

The head records and plays back by means of an electromagnet.

Carries the electric signals that represent image and sound

DIGITAL TAPE
is small, which makes it ideal for portable cameras. Digital tape combines magnetic tape with the data compression made possible by digital technology.

1.889 inches (48 mm)
2.598 inches (66 mm)

3. REPRODUCTION AND EDITING
What is recorded can be viewed by connecting the camera to a TV, a video recorder, or a printer to print photographs.

From Analog to Digital Technology

SUPER 8
Eastman Kodak developed an 8 mm-wide film inside a plastic cartridge. The film was used with a portable camera and a projector, and the format was very popular for home movies.
Duration 3 minutes

BETAMAX
Sony developed magnetic tapes that were of high quality but had little recording time. It continued to be manufactured for high-quality recordings until 2002.
Duration 60 minutes

VHS
The Video Home System was developed by JVC. Its advantages included re-recording most movies on a single tape, though some image quality was lost.
Duration 60 to 90 minutes

VIDEO 2000
This system of magnetic-tape cassettes used both sides of the tape, similar to audiotape. It was distributed by Philips until 1988.
Duration 8 hours

VHS SYSTEM
The VHS system became a standard for recording and viewing videocassettes. Home viewers and video clubs became popular.

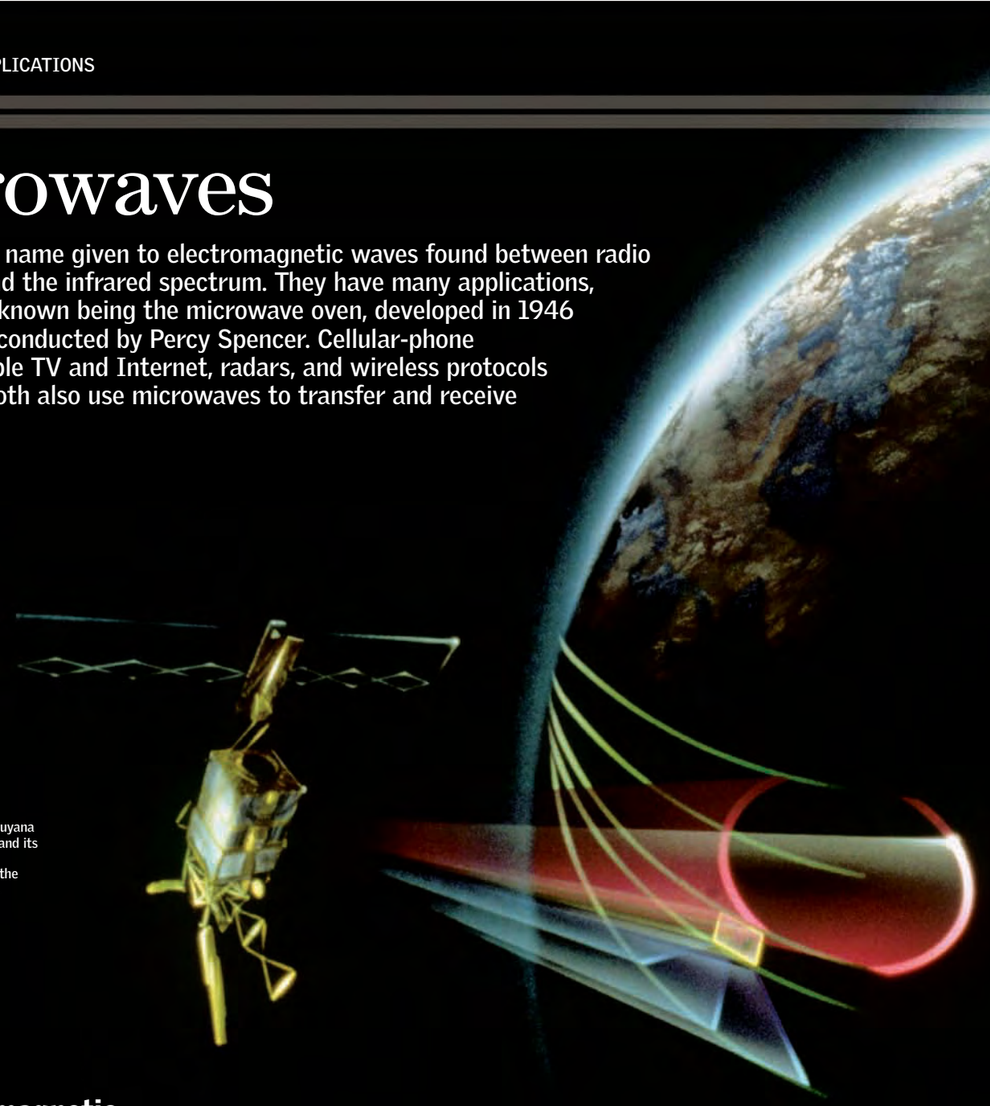
DVD
Philips and Sony introduced this digital disc. It can store every type of digital file, including high-definition video. A laser is used to view it.
Duration of up to 240 minutes

WEBCAMS
These small digital cameras connected to a computer can take photographs and record short videos. Connected to the Internet, they can be used in real time.

1965 1975 1976 1979 1980 1995 2000

Microwaves

This is the name given to electromagnetic waves found between radio waves and the infrared spectrum. They have many applications, the best known being the microwave oven, developed in 1946 from research conducted by Percy Spencer. Cellular-phone technology, cable TV and Internet, radars, and wireless protocols such as Bluetooth also use microwaves to transfer and receive information.



THE ERS-1 SATELLITE ORBITING EARTH
It was launched from the Guyana Space Center in July 1991, and its mission was to map the atmosphere and surface of the Earth by using microwaves.

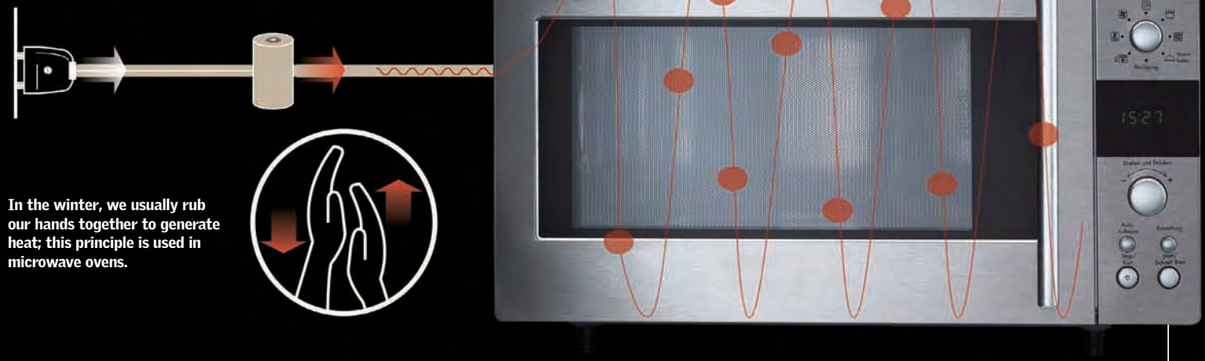
How a Microwave Oven Works

What it does is heat food by using high-frequency electromagnetic waves.

1 Electric plug
Transmits low-frequency electric current

2 Magnetron
The magnetron transforms electric energy into electromagnetic waves (high-frequency microwaves).

3 Microwave oven
The waves are distributed uniformly within the cavity, generating heat by the friction of the molecules present in food and liquids.



In the winter, we usually rub our hands together to generate heat; this principle is used in microwave ovens.

In Communications

According to the frequency and length of the wave used, the microwaves are also used in radio, TV, and cellular telephones.

CELLULAR TECHNOLOGY
allows communication between users whose locations are unknown or who are mobile. To this end, an infrastructure with base station antennas as its sole visible element must be set up.

1 Radio control
controls and assigns the functions related to radio waves. The geographic area in which the service is rendered is called the coverage area.

2 Base station
The station contains radio equipment that issues electromagnetic waves from communication antennas.

3 Cells and telephones
Each cell has a transmitting base station, which has multiple channels for the simultaneous use of dozens of phones. When a user passes from one cell to another, the phone leaves the frequency it was using and takes an available frequency in the new cell.

The Electromagnetic Spectrum

Electromagnetic energy has waves that have specific length and frequency within a continuous range known as the electromagnetic spectrum.

UNITS OF MEASUREMENT	
Length of the wave	Meters
Frequency	Hertz

ELECTRIC CURRENT

The frequency is a measure of the number of times that the electromagnetic field oscillates in one second.

The greater the wavelength, the less the energy.

Oscillation

The smaller the length of the wave, the greater the energy.

METERS	10^{5}	10^{4}	10^{3}	10^{2}	10^{1}	10^{0}	10^{-1}	10^{-2}	10^{-3}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}	10^{-16}
	RADIO WAVES			TV WAVES				MICROWAVES		INFRARED RADIATION	VISIBLE LIGHT		ULTRAVIOLET RADIATION		X-RAYS				GAMMA RAYS		

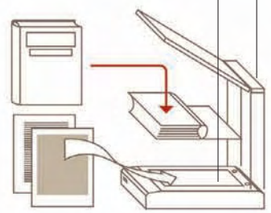
Scanners

Several technologies that digitize, read, detect, and trace images, objects, or signals can be grouped under this term. The better known are computer scanners and bar-code scanners, but scanners are also used in medicine, biometric identification, security systems, and detection of radio frequencies. Some computer scanners incorporate text-recognition software, which can digitize printed, typed, or even handwritten text. This capability has been very useful in digitizing a great amount of material at universities and libraries; however, it has also encouraged pirating in publishing.

How an Image Is Digitized

The scanner comes from the phrase "to scan." An image is scanned by a head that transforms it into digital data.

1. THE ORIGINAL
can be any document with a flat surface, such as a photograph, a paper document, or a page in a book.



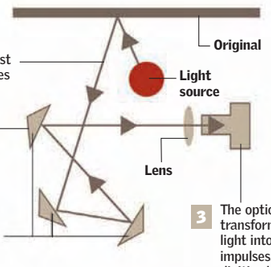
2. SCANNER HEAD
analyzes a photograph and converts it into digital information.

LINE BY LINE
The scanner head reads one small horizontal strip at a time.

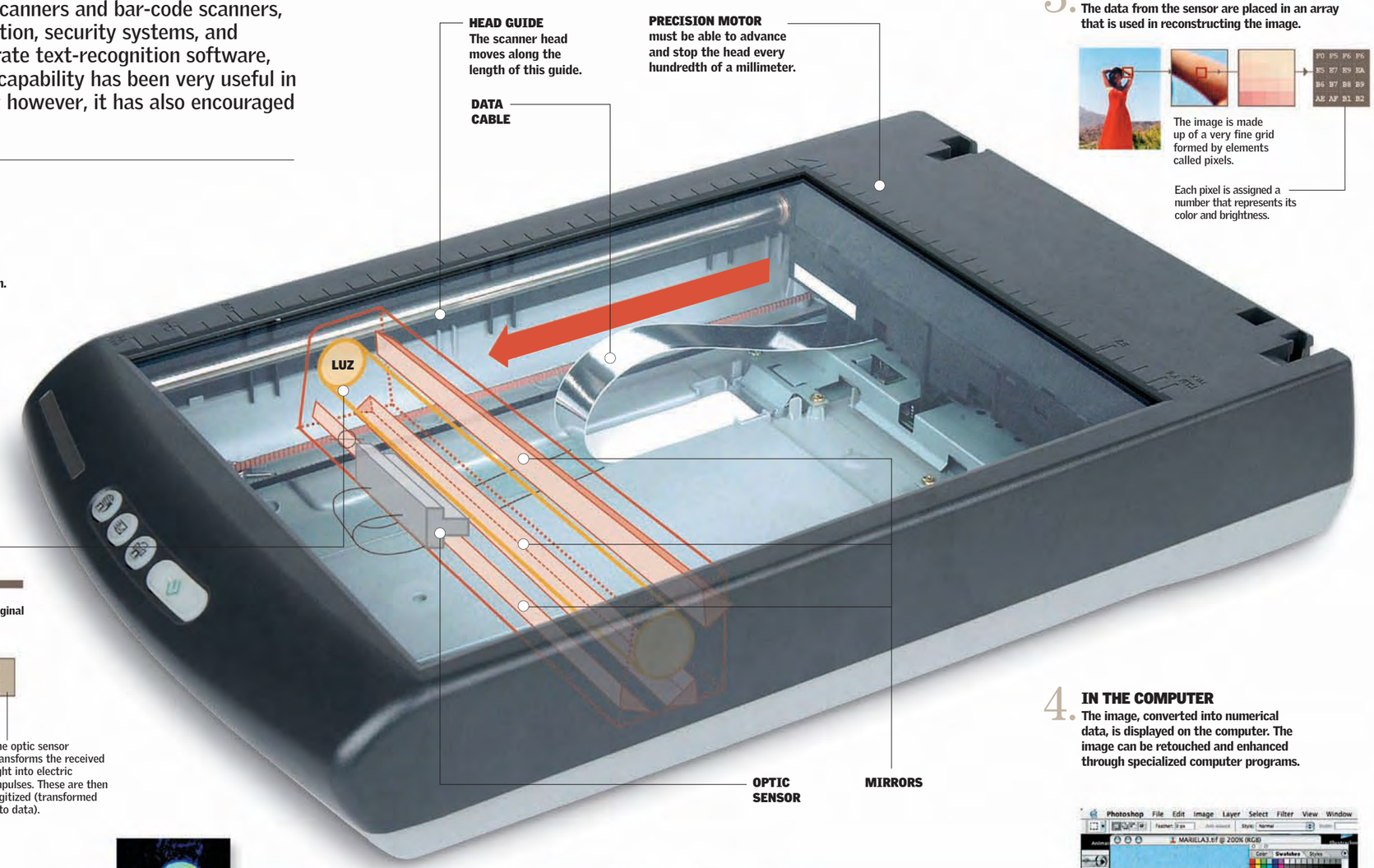
Once a strip is finished, the head moves and reads the following one.

Each strip can be less than 0.00039 inch (0.01 mm) thick.

HOW IT WORKS



1. Light bounces against the original and takes on its colors.
2. A system of mirrors and lenses concentrates this light in the optic sensor.
3. The optic sensor transforms the received light into electric impulses. These are then digitized (transformed into data).

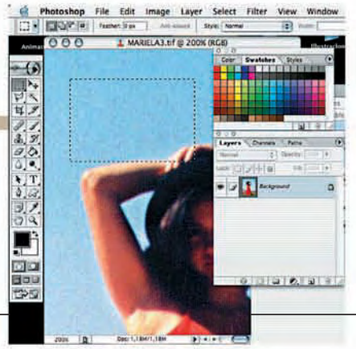


3. DIGITAL ARRAY
The data from the sensor are placed in an array that is used in reconstructing the image.

The image is made up of a very fine grid formed by elements called pixels.

Each pixel is assigned a number that represents its color and brightness.

4. IN THE COMPUTER
The image, converted into numerical data, is displayed on the computer. The image can be retouched and enhanced through specialized computer programs.

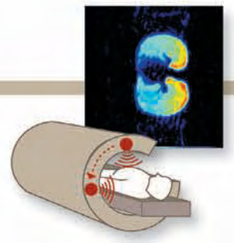


Other Types of Scanners

BAR CODES
A small scanner with a laser reads each bar and assigns a number according to its thickness, thus reproducing a numerical code.

The scanner that is used daily is the bar-code reader.

COMPUTERIZED TOMOGRAPHY
takes a series of X-rays of the body from different angles.



The computer reconstructs the image.

DIGITAL FINGERPRINTS
are made by tiny electric sensors that react in contact with skin.

The complete set of sensors reproduces the fingerprint.

Athletic Shoes

These shoes were already used in ancient times in Mesopotamia and Egypt, but they became widely used in the last decades of the 20th century. The first athletic shoes appeared in 1893. They were made of canvas and were used so that sailors did not need to walk with shoes along the docks. Today athletic shoes incorporate true technological advances designed to meet the needs of each sport. For instance, athletic shoes have begun to incorporate air chambers, located between the insole and the external covering of the sole that act as cushions to protect the foot.

Interior

Many different materials are used. Models for running must satisfy requirements for cushioning, stability, and ventilation.

13 ounces (390 g)
IS THE WEIGHT OF THIS ATHLETIC SHOE.

SIDE PANELS
For ventilation

METALLIC MESH
Ultrathin to ward off dust

HIGHLY ENGINEERED MESH
allows air but not dirt to pass through.

TOE CAP
provides a good fit and molds to the foot. Depending on the sport, it offers protection or low weight and breathability.

COUNTER
Made of a semirigid material, the reinforcement covers the heel internally and can prevent instability.

INSOLE
reduces excess heat and friction. Made of foam rubber or EVA to provide extra cushioning.

LATERAL MOVEMENT
is one of the most dangerous movements for sports people. A good shoe controls the natural movement of the foot. There are three types of footstep.

SUPINATION
needs flexible shoes and cushioning.
2 percent of the population

NEUTRAL
Correct and without any disorders
24 percent of the population

PRONATION
leans toward the inside because of a person being flat-footed or overweight.
74 percent of the population

CUSHIONING SYSTEM
Viscous cushioning material, placed in the area of impact for running

MIDSOLE
joins the front toe cap (to which it is sewn) with the insole (to which it is glued).

FASTENING SYSTEM
Shoelaces, zippers, or Velcro. They must fasten the shoe in such a way that the foot can flex in movement.

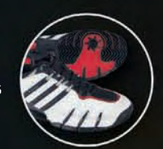
CHASSIS
Used for reinforcement The openings provide airflow.

INNER SOLE
Their function is to provide comfort and stability and to support the foot. They must be light and flexible.

TOE GUARD
Protection from rubbing against the toe cap

SOLE
can be made of solid or natural rubber. Some include air bubbles that compress when impacted. Each sport requires a different design whose main function is to provide a good grip on the surface.

Track shoes include nails, and soccer shoes include cleats that can sink into the soil for a better grip.



Biomechanics of Racing

1 IMPACT
When running, the movement of the foot is cyclic. It requires the cushioning of the heel, the part of the foot that undergoes repeated impact.

The heel hits the ground with a force three to four times the weight of the body.

2 LANDING
With support, the foot naturally rotates inward (pronation). The stabilizing elements prevent excessive pronation.

3 IMPULSE
The pressure shifts from the heel to the front of the foot, which is compressed as it pushes off the ground.

Breakthrough Inventions

THE FIRST COMPUTER
The Electronic Numerical Integrator and Computer (ENIAC) was invented in the 1940s and weighed 30 tons, occupied 1,800 square feet (170 sq m), and required a total of 17,468 electronic valves for its operation.

SKYSCRAPERS 30-31
THE CELLULAR TELEPHONE 32-33
GPS 34-35
THE COMPUTER CHIP 36-37
THE COMPUTER 38-39
THE INTERNET 40-41
CINEMATOGRAPHY 42-43
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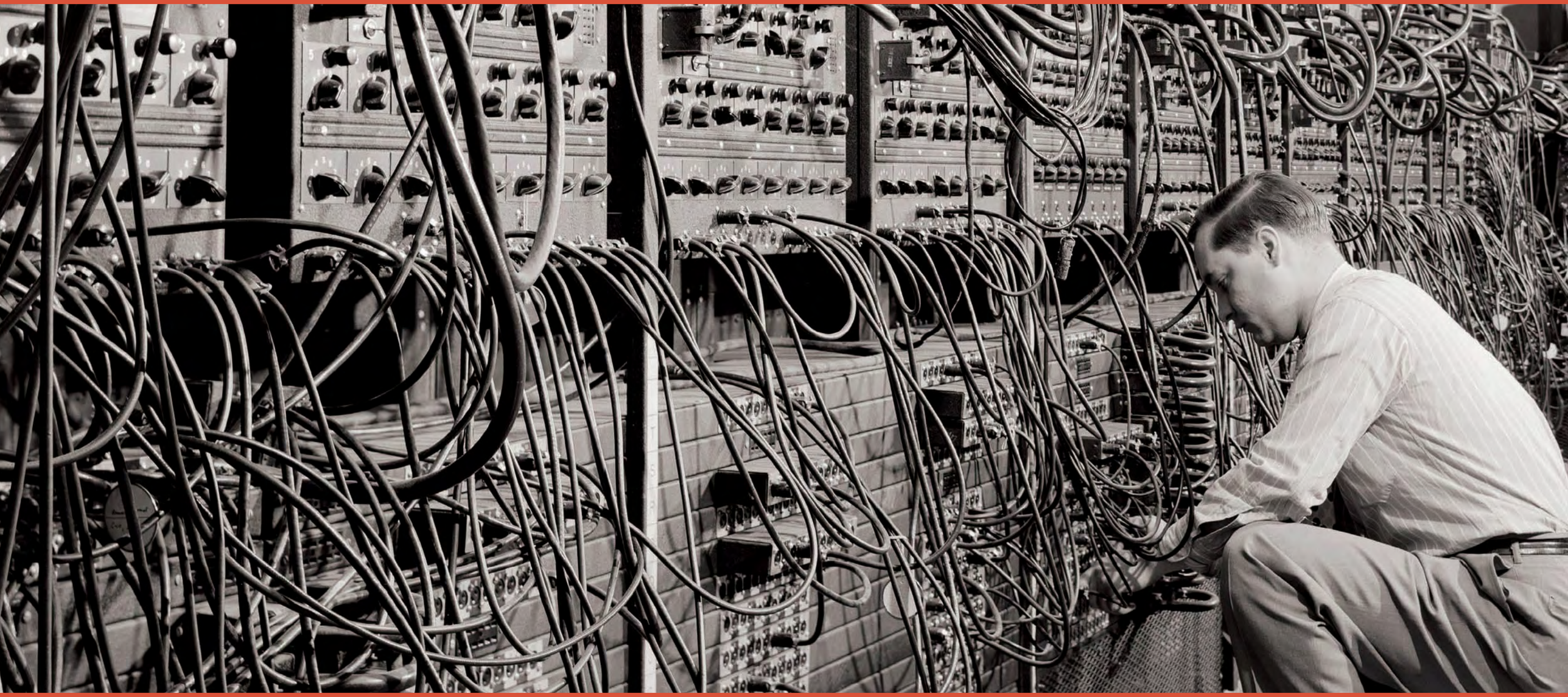


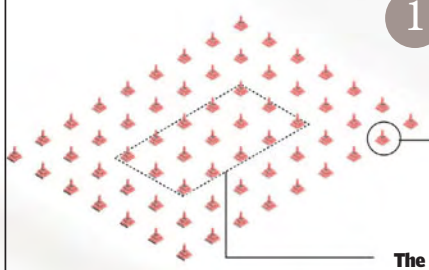
In the history of technology, there are milestone inventions that radically changed the world and the way we perceive it. Many of these inventions, such as cinematography or the radio, are the realization of the longtime hopes and dreams of humankind. Others, such as the Internet, the cellular telephone, or GPS, have transformed the way we communicate and have dramatically shortened distances between people. Inventions such as the printing press and the computer chip led to the dramatic development of the arts and sciences, enabling in turn the appearance of more new technologies. Others, such as computers, have not only become indispensable tools, but they have also led us to question the nature of intelligence.

Skyscrapers

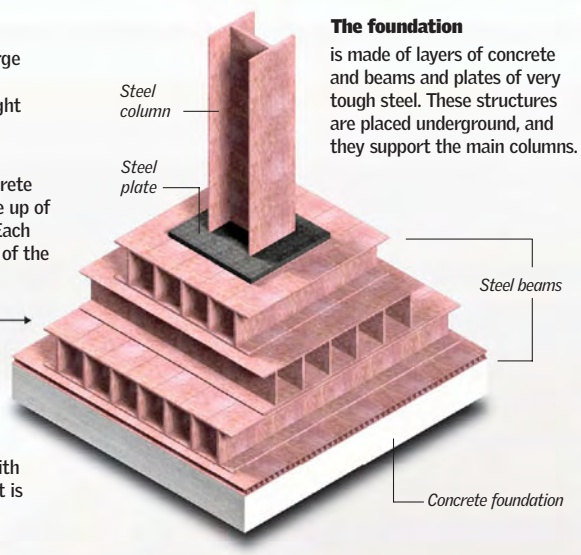
The development of new materials—especially high-performance concrete and steel—has led to the design and construction of buildings to heights never achieved before. For architects and engineers who work on the construction of large skyscrapers, the greatest challenges lie in ensuring the adequate delivery of services, from elevator systems and gas and water lines to complex emergency systems. There is also a new issue to deal with: how to make the structures less vulnerable to potential terrorist attacks, especially after the September 11, 2001, attacks in New York City.

From the Ground to the Sky

The construction of a skyscraper begins with the digging of a large pit for the foundation that will support the entire edifice. This structure of concrete and steel has to take into consideration the weight of the building, lateral resistance to winds, and, possibly, earthquakes.

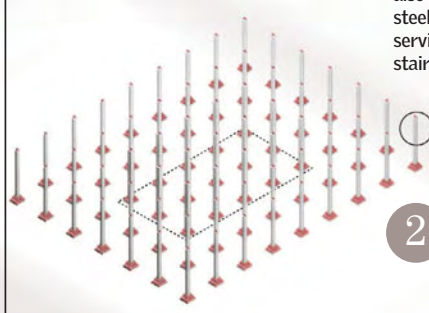


1 The steel and concrete foundation is made up of a series of bases. Each base supports one of the main columns.



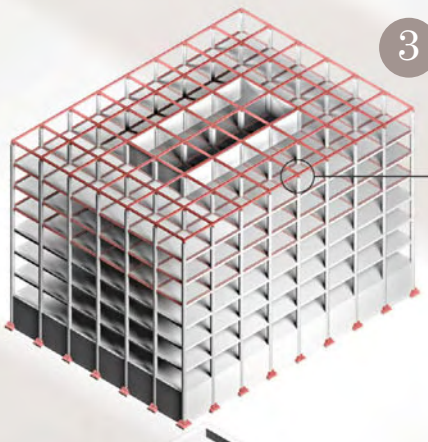
The foundation is made of layers of concrete and beams and plates of very tough steel. These structures are placed underground, and they support the main columns.

The core provides the skyscraper with strong lateral resistance. It is also made of concrete and steel and generally houses service elements (elevators, stairways, etc.).

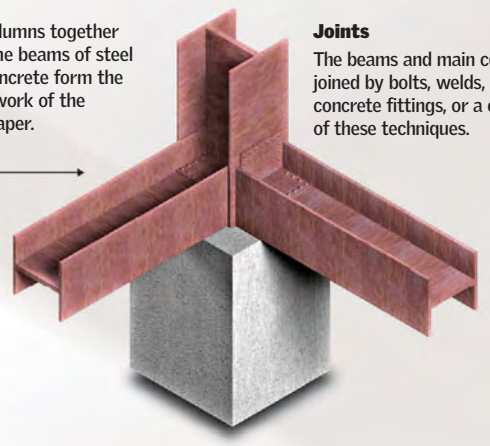


2 The weight of the building rests upon columns made of high-performance, reinforced concrete.

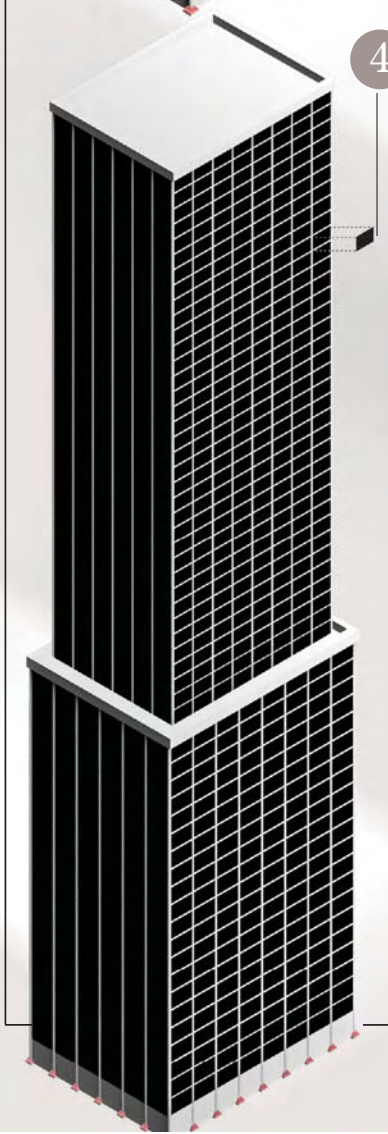
Reinforced concrete is the basic material in modern construction. It consists of a layer of concrete with an internal steel structure that gives it extraordinary resistance.



3 The columns together with the beams of steel and concrete form the framework of the skyscraper.



Joints The beams and main columns are joined by bolts, welds, rivets, concrete fittings, or a combination of these techniques.



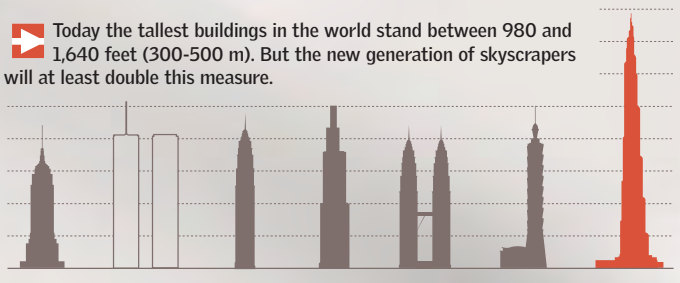
4 Finally, the curtain wall is built over the framework. It is typically made of glass panels, although other materials are also used.

Concrete

High-performance concrete is manufactured by using finer particles and adding special chemicals. Because of its increased resistance, smaller amounts of concrete are needed.

The Tallest in the World

Today the tallest buildings in the world stand between 980 and 1,640 feet (300-500 m). But the new generation of skyscrapers will at least double this measure.



Empire State Building *(U.S.)* **1,250 feet (381 m)**	World Trade Center *(U.S.)* **1,368 feet (417 m)** —destroyed in 2001	Jin Mao Tower *(China)* **1,377 feet (420 m)**	Sears Tower *(U.S.)* **1,450 feet (442 m)**	Petronas Twin Towers *(Malaysia)* **1,483 feet (452 m)**	Taipei 101 *(Taiwan)* **1,667 feet (508 m)**	Burj Dubai *(U.A.E.)* **more than 2,600 feet (800 m)**

The Uncertain Primacy of the Burj Dubai

The record set by Burj Dubai could be short-lived if the planned construction of the Al Burj, also in Dubai and with a planned height of 3,940 feet (1,200 m), goes forward.

The Burj Dubai

is the tallest building in the world and is currently under construction in Dubai, United Arab Emirates. Its final height has been kept secret to avoid potential competition, but it is believed that it will be anywhere from 2,625 to 3,280 feet (800-1,000 m).

TECHNICAL SPECIFICATIONS

- **Height:** Between 2,625 and 3,280 feet (800-1,000 m)
- **Floors:** 181 to 216
- **Elevators:** 3,445 feet per minute (1,050 m/min) or 40 miles per hour (65 km/h) (they will be the fastest in the world)
- **Structure:** High-performance concrete reinforced with steel
- **Exterior:** Glass with solar filters, aluminum, and stainless steel
- **Volume of concrete:** 9,181,810 cubic feet (260,000 cu m)
- **Reinforced steel:** 34,000 tons
- **Projected cost:** $876 million
- **Weight:** The building's weight will equal that of 100,000 elephants.

FLEXIBILITY

Strong winds can cause tall skyscrapers to sway. The Burj Dubai building, given its height, will be particularly vulnerable to this phenomenon.

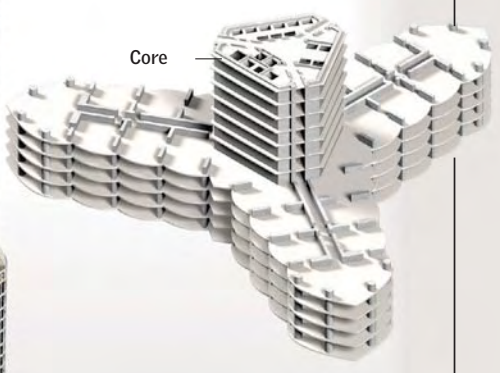
Height	Sway
1,985 feet (605 m)	5 feet (1.5 m)
1,870 feet (570 m)	4 feet (1.25 m)
1,450 feet (442 m)	2.5 feet (.75 m)
1,230 feet (375 m)	2 feet (.5 m)

248,320

The number of gallons of water that will be required to supply the daily demand at the Burj Dubai skyscraper

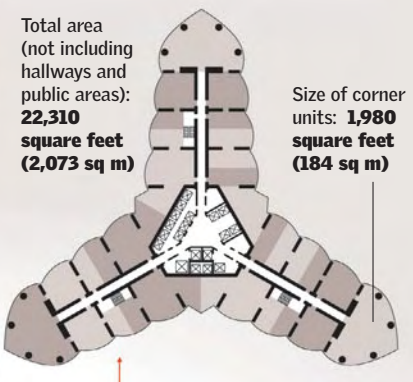
STRUCTURE

The base of the building is designed in a Y shape. In addition to providing structural strength, this design provides more area for windows. Prior to construction, the structure was rotated according to the prevailing winds to reduce structural stress.



SAMPLE FLOOR PLAN

Distribution of units/rooms



The Cellular Telephone

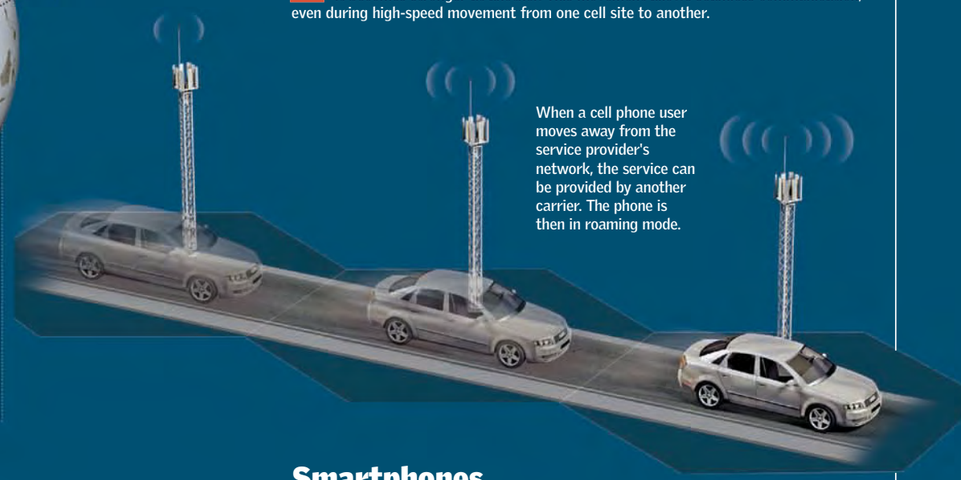
Few inventions have had as widespread an impact as the cellular phone. In just two-and-a-half decades, the cellular phone has become extremely popular around the world and almost indispensable for populations in the developed world, to the point that sales already surpass one billion units a year. The latest cell phones, in addition to being small, portable, and light, are true workstations that far exceed their original function of keeping the user connected at any time and place.

INTERNATIONAL CALLS

As is the case with landline phones, international communications are facilitated with the assistance of satellites.

In Motion

Cell sites detect the movement of a cell phone; as the signal weakens at one site, it becomes stronger at another. This movement allows seamless communication, even during high-speed movement from one cell site to another.



When a cell phone user moves away from the service provider's network, the service can be provided by another carrier. The phone is then in roaming mode.

Communication

Providers divide an area into a system of cell sites. Each site has an antenna that detects the presence of a particular cell phone in its area and identifies it through the phone's unique code.

1 Calling

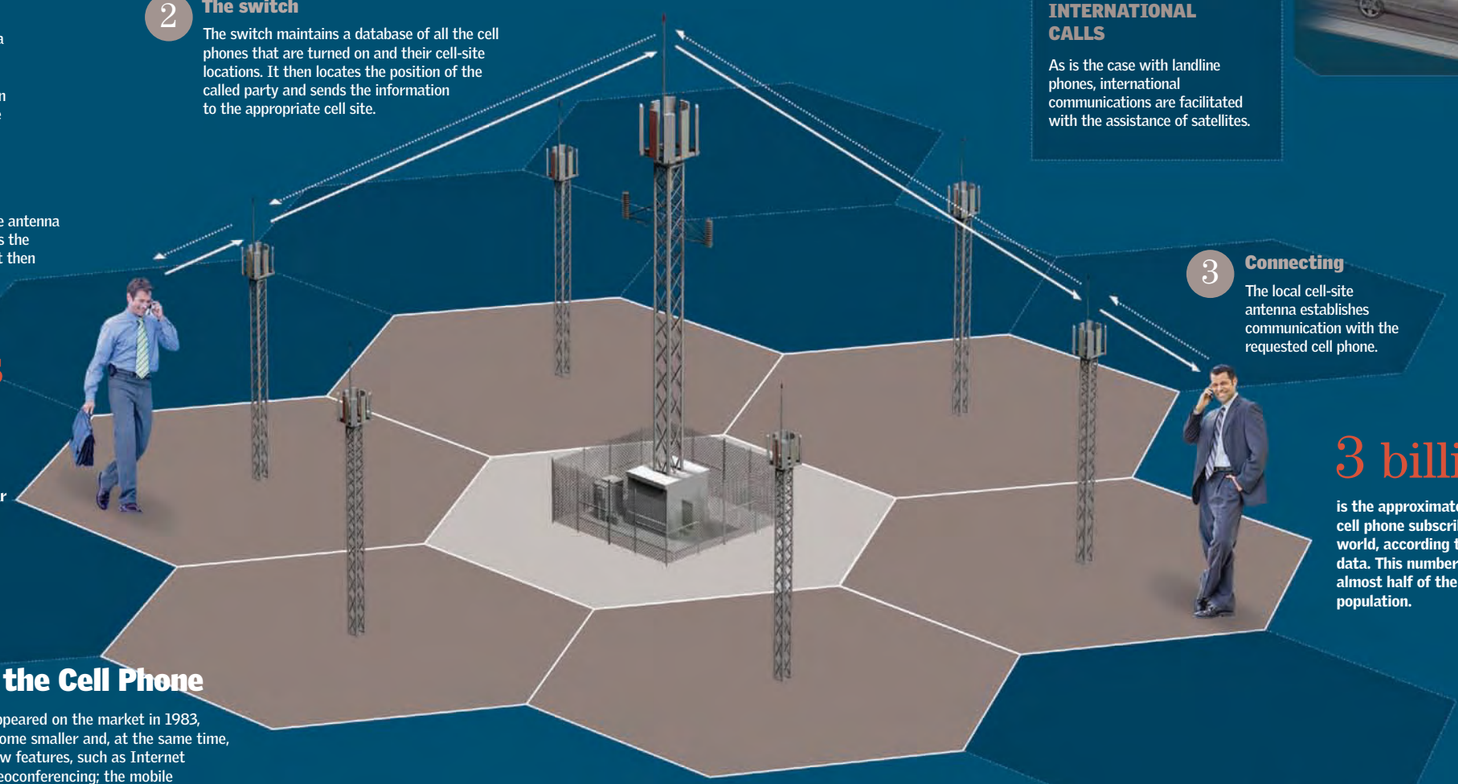
When a number is dialed, the antenna at the local cell site identifies the caller and the called party. It then transmits this information to the switch.

2 The switch

The switch maintains a database of all the cell phones that are turned on and their cell-site locations. It then locates the position of the called party and sends the information to the appropriate cell site.

3 Connecting

The local cell-site antenna establishes communication with the requested cell phone.



28 ounces (780 g)

is the weight of the Motorola DynaTAC 8000X, which was the first commercially available cellular phone. More recent models weigh less than 2 ounces (50 g).

3 billion

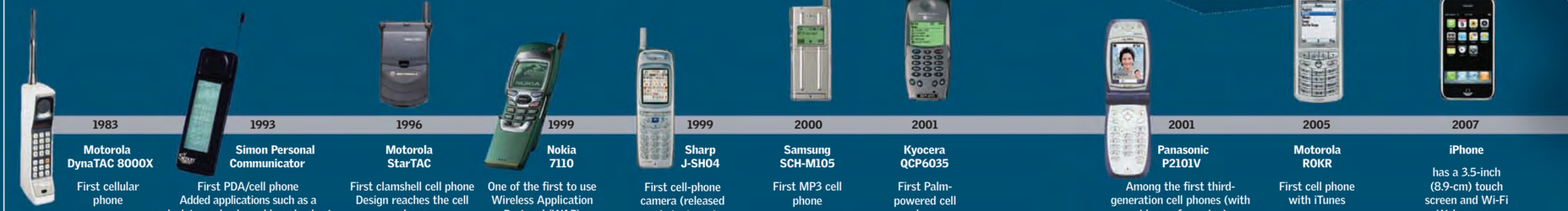
is the approximate number of cell phone subscribers in the world, according to the latest data. This number is equal to almost half of the world population.

Smartphones

In addition to being a telephone and having such traditional features as a calendar, calculator, and camera, a smartphone incorporates advanced computing capabilities for connecting to the Internet through Wi-Fi and to other devices through Bluetooth.

The Evolution of the Cell Phone

Since the first cell phone appeared on the market in 1983, mobile telephones have become smaller and, at the same time, they have incorporated dozens of new features, such as Internet connectivity, picture taking, and videoconferencing; the mobile telephones also play music.



1983 — Motorola DynaTAC 8000X
First cellular phone

1993 — Simon Personal Communicator
First PDA/cell phone
Added applications such as a calculator, calendar, address book, etc.

1996 — Motorola StarTAC
First clamshell cell phone
Design reaches the cell phone

1999 — Nokia 7110
One of the first to use Wireless Application Protocol (WAP)

1999 — Sharp J-SH04
First cell-phone camera (released only in Japan)

2000 — Samsung SCH-M105
First MP3 cell phone

2001 — Kyocera QCP6035
First Palm-powered cell phone

2001 — Panasonic P2101V
Among the first third-generation cell phones (with videoconferencing)

2005 — Motorola ROKR
First cell phone with iTunes

2007 — iPhone
has a 3.5-inch (8.9-cm) touch screen and Wi-Fi Web access.

GPS

The Global Positioning System (GPS) allows a person to locate his or her position anywhere on the planet, at any time, using a small handheld receiver. Originally developed as a military project, GPS has now reached every corner of civilian life. Today it is not only an essential tool in ships and aircraft, but it is also becoming, due to its multiple applications, a common feature in vehicles as well as in athletic and scientific equipment.

Features

Since GPS is a dynamic system, it also provides real-time data about the movement, direction, and speed of the user, allowing for a myriad of uses.

1 **Location**
The civilian user determines his or her position using three-dimensional geographic coordinates, with a margin of error between 7 and 50 feet (2-15 m) depending on the quality of the receiver and the satellites it detects at any given moment.

2 **Maps**
Extrapolation of the coordinates using geographic charts of cities, roads, rivers, oceans, and airspace can produce a dynamic map of the user's position and movement.

3 **Tracking**
The user can know the speed at which he or she is traveling, the distance traveled, and the time elapsed. In addition, other information is provided, such as average speed.

4 **Trips**
Trips can be programmed using predetermined points (waypoints). During the trip, the GPS receiver provides information about the remaining distance to each waypoint, the correct direction, and the estimated time of arrival.

APPLICATIONS

Although it was originally developed as a navigational system, GPS is used today in a variety of fields. The free use of this tool for work, business, recreation, and sports activities is changing the way we move and act.

SPORTS
GPS devices keep the athlete informed on time, speed, and distance.

MILITARY
Used in remote-controlled and navigational systems

SCIENTIFIC
Used in paleontology, archaeology, and animal tracking

EXPLORATION
Provides orientation and marks reference points

TRANSPORTATION
Air and maritime navigation. Its use is growing in automobiles.

AGRICULTURE
Maps areas of greater or lesser fertility within different plots of land

Satellites, Lighthouses in the Sky

The Navstar GPS satellites are the heart of the system. The satellites emit signals that are interpreted by the GPS receiver to determine its location on a map. The system has a constellation of 24 main satellites that orbit the Earth at an altitude of 12,550 miles (20,200 km), collectively covering the entire surface of the planet. They circle the Earth every 12 hours.

1 The receiver detects one of the satellites and calculates its distance. This distance is the radius of a sphere whose center is the satellite and on whose surface the user can be located, although at a point yet to be determined.

2 When a second satellite is detected and the distance calculated, a second sphere is formed that intersects with the first sphere along a circle. The user can be located anywhere along the perimeter of this circle.

3 A third satellite forms a third sphere that intersects the circle at two points. One of the points is ruled out as an invalid location (for example, a position above the surface of the Earth). The other point is the correct location. The more satellites used, the lower the margin of error.

Clocks

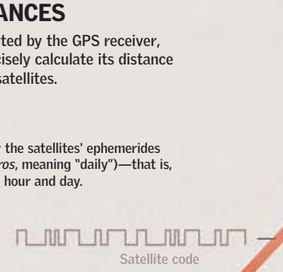
Thanks to data received from the satellites, civilian GPS receivers also function as atomic clocks (the most precise in the world), although several thousands of dollars cheaper.

CALCULATING DISTANCES

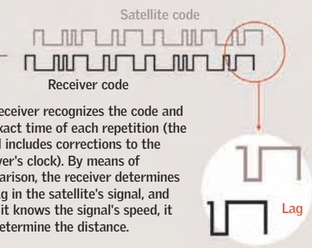
Once the GPS satellites are detected by the GPS receiver, the receiver's challenge is to precisely calculate its distance and position in relation to those satellites.

1 The receiver has in its memory the satellites' ephemerides (from the Greek word *ephemeros*, meaning "daily")—that is, their position in the sky by the hour and day.

2 Upon detection of a satellite, it receives a highly complex signal of on-off pulses called a pseudo-random code.



Each satellite has its own code that helps the receiver identify it. The code travels at the speed of light.



3 The receiver recognizes the code and the exact time of each repetition (the signal includes corrections to the receiver's clock). By means of comparison, the receiver determines the lag in the satellite's signal, and since it knows the signal's speed, it can determine the distance.

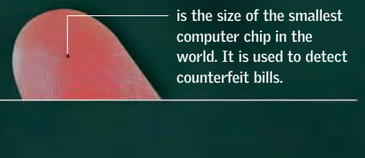
750 **The annual cost, in millions of dollars, to maintain the entire Global Positioning System.**

The Computer Chip

Without this small electronic device, the majority of new technologies from the past few years would not exist. The computer chip is present in myriad objects used every day. Despite its limited dimensions, each chip contains thousands or millions of interconnected electronic devices (mainly diodes and transistors) and also passive components (such as resistors and capacitors). Its invention was made possible with the discovery that semiconductor elements could accomplish the same functions as vacuum tubes but with a much superior performance and at considerably lower cost.

What It Is

It is a thin silicon wafer that measures less than half an inch (1.3 cm) across and can contain several million electronic components.



0.02 inch (0.6 mm) is the size of the smallest computer chip in the world. It is used to detect counterfeit bills.

SOME APPLICATIONS

HOME	Microwave ovens, digital clocks
OFFICE	Computers, calculators
COMMUNICATIONS	Telephones, TV, radio
TRANSPORTATION	Air and land traffic control
MEDICINE	Diagnostic equipment
ENTERTAINMENT	Audio, video games
MILITARY	Weapons

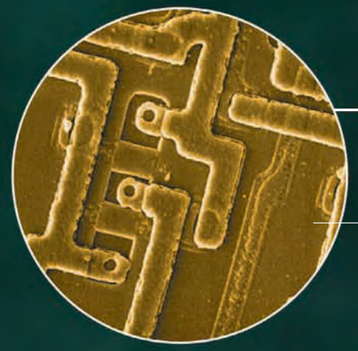
SIZE REDUCTION

Continuing improvements in the techniques of computer-chip fabrication have allowed the development of ever-tinier electronic components.

TRADITIONAL TRANSISTOR
Simple capsule

CHIP
can contain millions of transistors.

ACTUAL SIZE

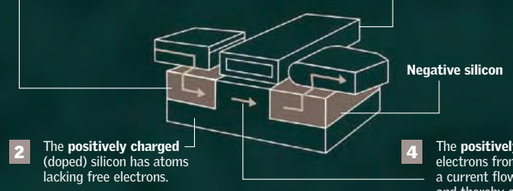


TRANSISTOR
Etched in the silicon, the transistor is a very effective semiconductor device and amplifier, but microscopic in size. The smallest ones measure 50 nanometers.

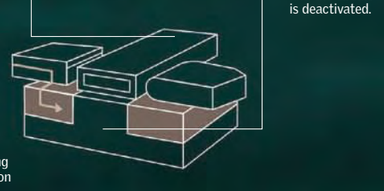
HOW TRANSISTORS WORK

Transistors act like electronic switches that are activated and deactivated by means of an electrical signal.

ACTIVE CIRCUIT



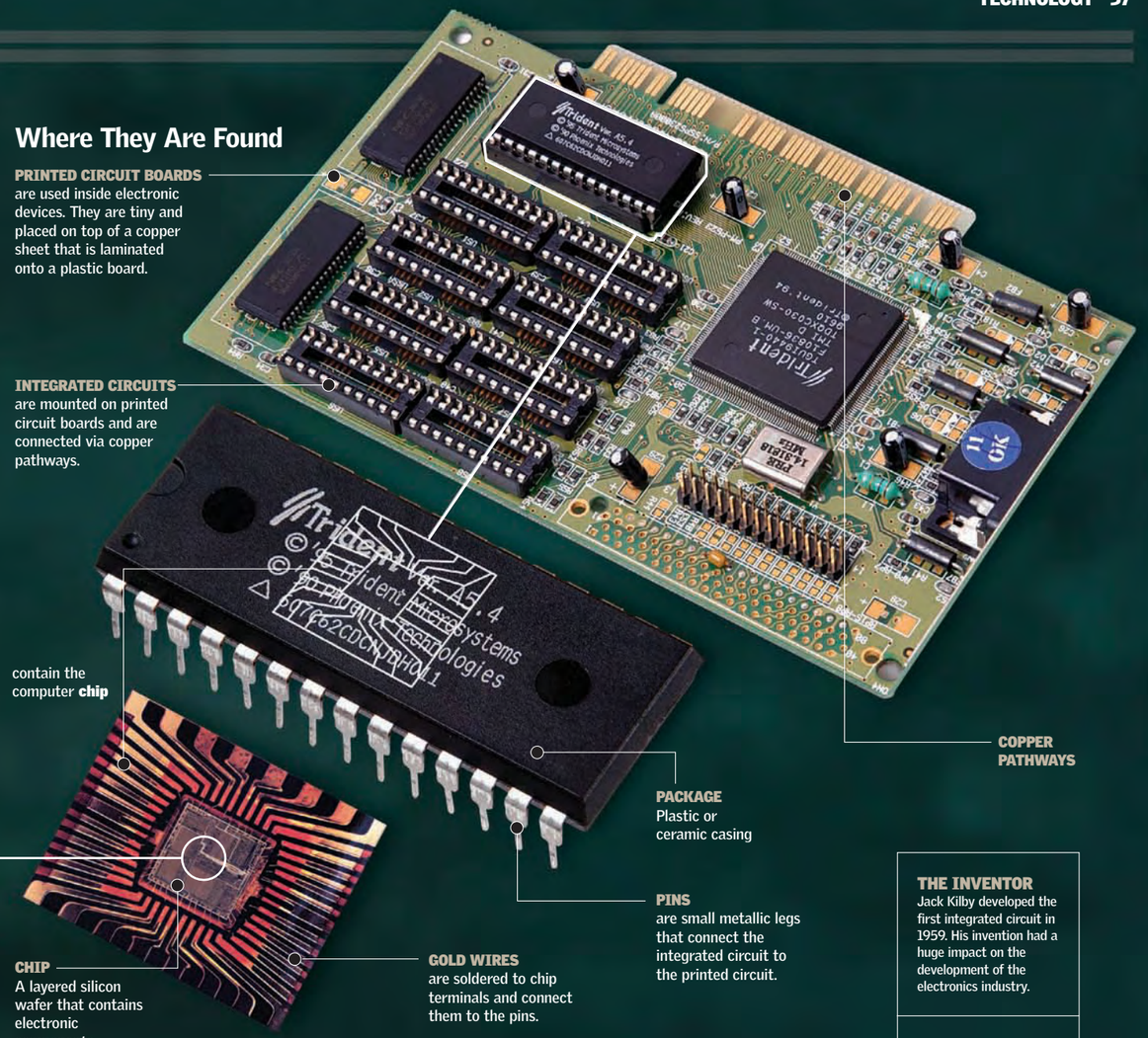
INACTIVE CIRCUIT



Where They Are Found

PRINTED CIRCUIT BOARDS are used inside electronic devices. They are tiny and placed on top of a copper sheet that is laminated onto a plastic board.

INTEGRATED CIRCUITS are mounted on printed circuit boards and are connected via copper pathways.



contain the computer **chip**

COPPER PATHWAYS

PACKAGE
Plastic or ceramic casing

PINS
are small metallic legs that connect the integrated circuit to the printed circuit.

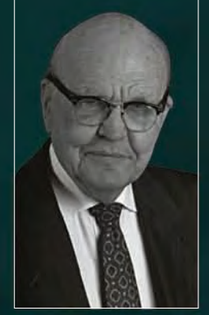
GOLD WIRES
are soldered to chip terminals and connect them to the pins.

CHIP
A layered silicon wafer that contains electronic components

THE INVENTOR

Jack Kilby developed the first integrated circuit in 1959. His invention had a huge impact on the development of the electronics industry.

Jack Kilby
Electrical engineer from the United States. He was awarded the Nobel Prize for Physics in 2000.



Evolution of the Computer Chip

YEAR	MODEL	TRANSISTORS
1971	4004	**2,250**
1978	8086	**29,000**
1985	386	**275,000**
1989	486	**1,180,000**
1993	PENTIUM	**3,100,000**
2000	PENTIUM 4	**42,000,000**

First Integrated Circuit

GLASS SUBSTRATE
This is where the components are placed.

GERMANIUM WAFERS
contained a single transistor and other circuit components of an audio oscillator.

WIRE CONNECTORS

The Computer

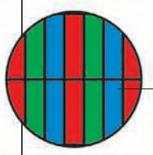
From the huge calculating machines that occupied entire rooms to today's home and laptop models, computers have revolutionized how we see the world and relate to it. Today our everyday lives are characterized by information technology, whether for recreation, work, study, or communication. Already under development are quantum computers and so-called molecular computers, which are biocomputers that use DNA as the basis of their circuits and that have the ability to replicate themselves.

LAPTOP MODELS
have a rechargeable battery and smaller dimensions. They basically have the same features as a PC.

The Personal Computer

is made up of various interconnected devices (the hardware) and programs (the software). The core is a very powerful microprocessor that contains all the devices and is installed on the motherboard.

PROGRAM
is the component most closely related to the user. It is also known as application software. It allows the user to accomplish tasks, such as processing text and images, performing calculations, managing databases, and using the Internet.



MONITOR
The images are formed by tiny cells called pixels, which use the additive primary colors red, green, and blue. High-resolution monitors can have an array of up to 1,920 x 1,200 pixels.

OPERATING SYSTEM
Windows is the one most commonly used. It presents the system in a user-friendly way, using icons, folders, and windows.

STORAGE DEVICES
are used to save information or transport information to another computer.

CD/DVD READER/RECORDER
reads and also records CDs and DVDs.

HARD DISK
saves programs and folders as permanent, magnetically recorded data.

FLOPPY DRIVE
reads and records information on flexible floppy disks (diskettes).

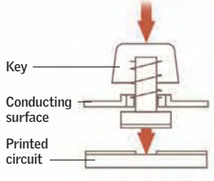
COMPUTER TOWER
is the case that holds the main components.

CONNECTORS
are used to connect peripheral devices, such as a modem, scanner, or printer.

USB PORT

PARALLEL PORT

ACCESS DEVICES



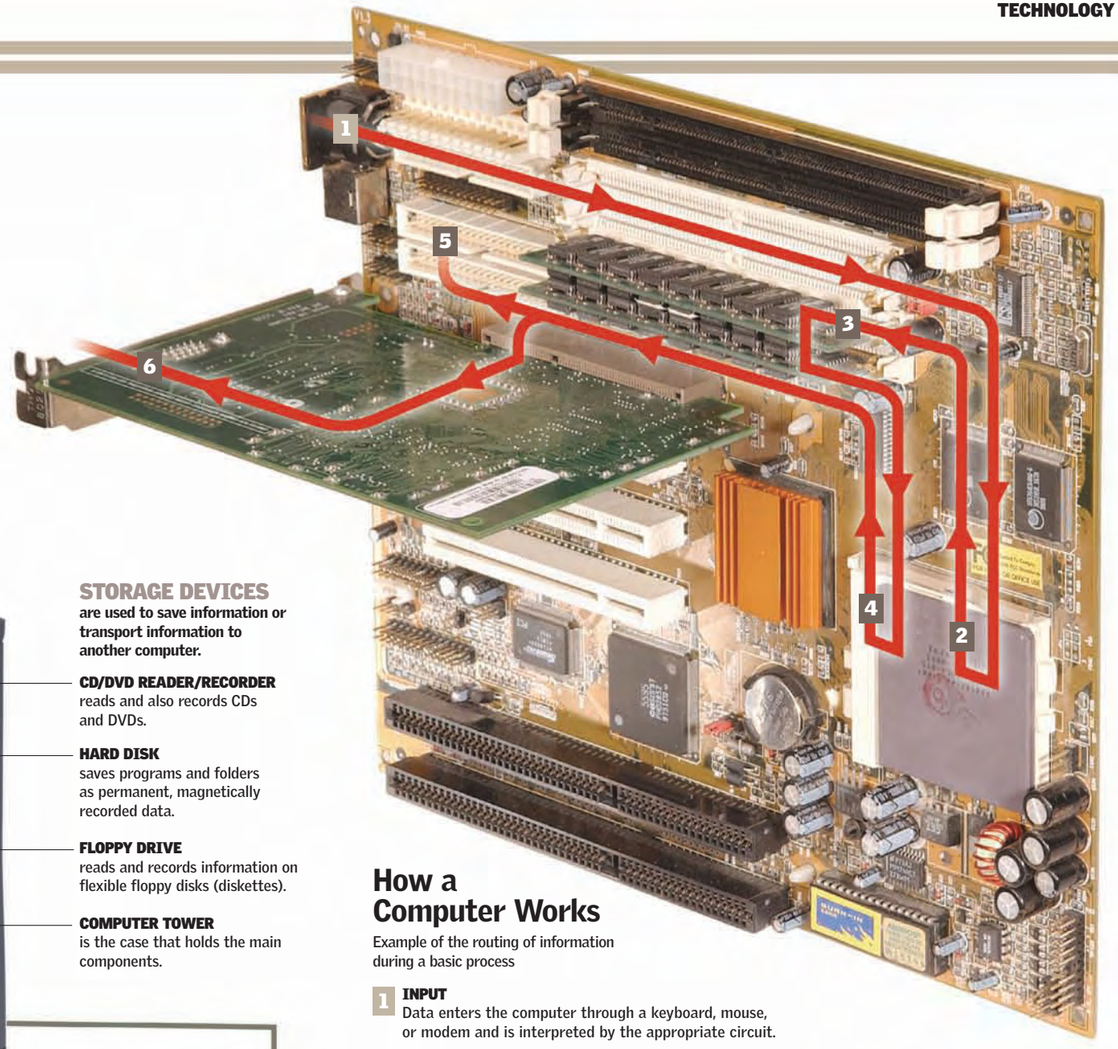
KEYBOARD
It is used to enter data (numbers, letters, and symbols) by sending coded signals to the microprocessor. When a key is pressed, a contact is closed.

UNDERSIDE

A video camera registers movement.

A light-emitting diode (LED) illuminates the surface beneath it.

OPTICAL MOUSE
controls the placement of the cursor in the computer's graphic interface. It registers any movement of the mouse and calculates the coordinates of the movement.



How a Computer Works

Example of the routing of information during a basic process

1. **INPUT**
Data enters the computer through a keyboard, mouse, or modem and is interpreted by the appropriate circuit.

2. **MICROPROCESSOR**
controls all computer functions. It processes the entered data and carries out the necessary arithmetic and logic calculations.

3. **RAM MEMORY**
temporarily stores all the information and programs used by the microprocessor.

4. **PROCESSING**
Data can travel back and forth from the CPU to the RAM several times until processing is complete.

5. **STORAGE**
Data is sent to a storage device (for example, the hard disk).

6. **OUTPUT**
The information on the monitor is updated through the video card.

Essential Components

MOTHERBOARD
The main printed circuit board to which all other hardware components are connected

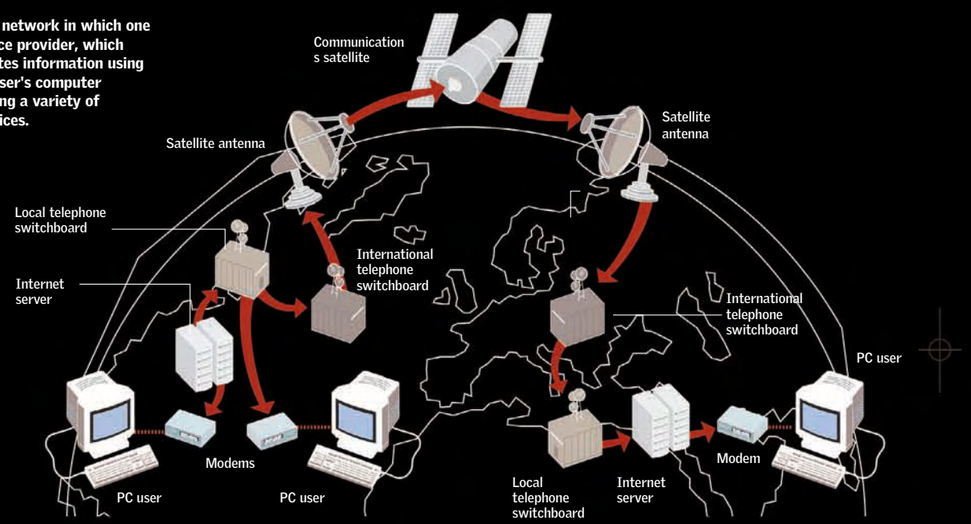
ROM MEMORY
(Read Only Memory)
Used to store the basic startup instructions for the computer

EXPANSION SLOTS
allow for the insertion of circuit boards to incorporate more devices.

The Internet

Is a worldwide network where interconnected computers of every type can exchange information. The social impact of the Internet is comparable to the invention of the printing press, enabling the free flow of information and access to it from anywhere in the world. With the appearance of blogs, the world of editing and journalism has become democratic, since virtually anyone can publish their own texts, images, and opinions.

HOW IT IS SET UP
The Internet is a worldwide network in which one participates through a service provider, which receives, saves, and distributes information using its computer "server." The user's computer connects to the Internet using a variety of methods, programs, and devices.



THE BROWSER
is a program that allows the user to see documents on the World Wide Web and to go from one document to another using the hypertext transfer protocol (HTTP). The most common browsers are Internet Explorer, Netscape, and Firefox.

A WEB SITE OR WEB PAGE
contains a series of documents written in hypertext markup language (HTML) combined with other, more sophisticated languages, such as Java and Flash animation.

ELECTRONIC MAIL
travels from one computer to another through e-mail servers. It can carry attachments, such as photos or text documents.

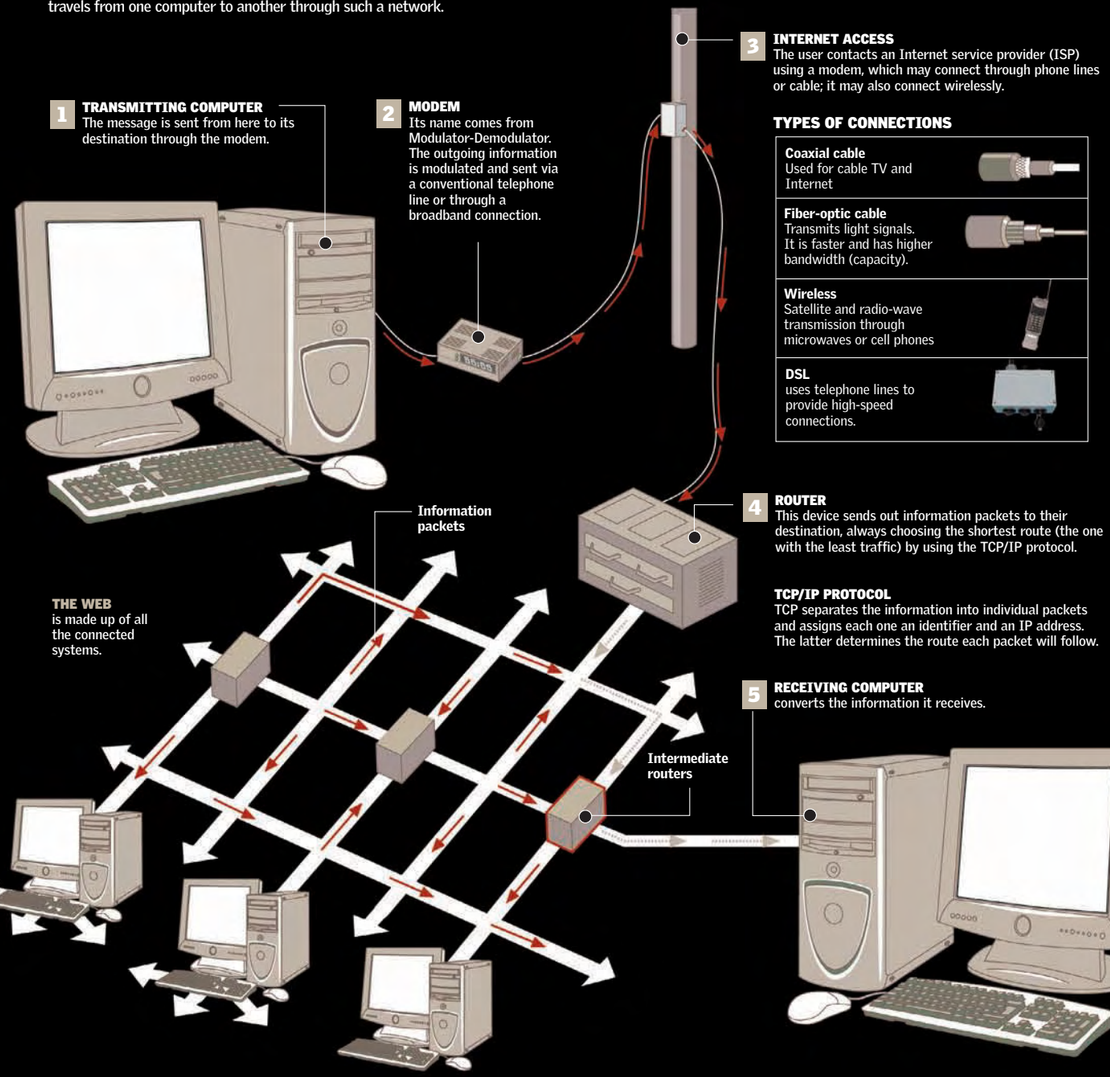
SEARCH ENGINES
are tools used to find information available on the World Wide Web. They function like a database that is constantly being updated by robots that prowl the Web and collect information. The most commonly used search engines are Google and Yahoo; they also offer other services to their users, such as e-mail and news updates.

CHAT
This service allows a group of users to communicate with each other in real time. It started out only in written form, but it is now possible to transmit audio and video images via webcams.

VOICE OVER IP
is a system that allows a computer to communicate with a regular telephone anywhere in the world, bypassing normal telephone charges. It requires an Internet connection and a program that enables this type of communication.

Transmitting Information

These interconnected systems share information internally and with external users, forming networks. Information travels from one computer to another through such a network.



Cinematography

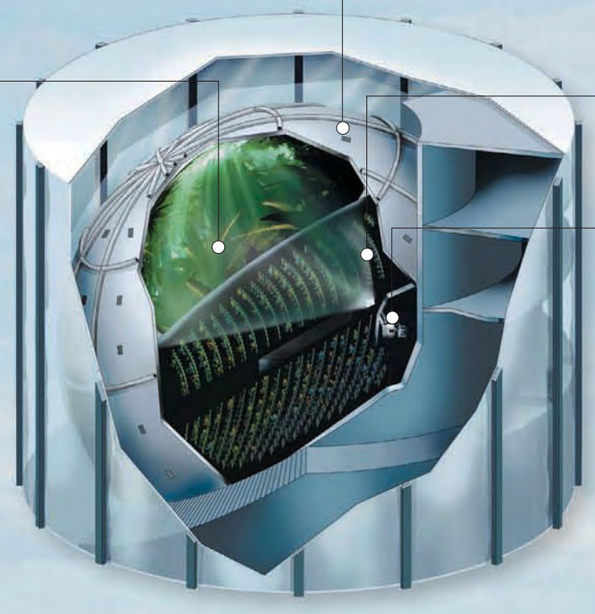
Since the middle of the 19th century, the desire to produce moving images has resulted in the development of a large variety of mechanical devices, such as the praxinoscope and the zoetrope. The appearance of celluloid film allowed real images to be captured to show movement. The introduction of sound was a revolutionary innovation, even more so than the introduction of color. The idea of three-dimensional images has also been pursued, with mixed results. Today IMAX technology allows viewers to become immersed in the film they are watching.

IMAX Technology

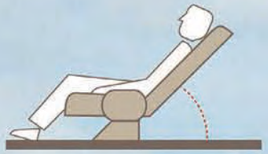
is the most advanced motion-picture projection system. Invented in Canada, it is used in more than 228 movie theaters across North America and Europe. As of today, only four theaters have all three projection systems: IMAX, Omnimax, and IMAX 3-D.

Omnimax

THE SCREEN
is metallic, hemispherical, and white. It wraps over the seats like a dome. It takes four minutes just to open it.



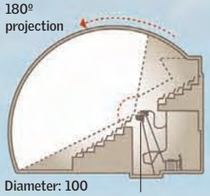
SOUND
27,000 watts of power
Sound passes through small holes in the screen and travels throughout the whole theater.



SEATS
The seats recline and the viewer cannot see the edge of the screen, creating the feeling of being immersed in the movie.

THE PROJECTOR
The system provides greater image stability.

180º projection



Diameter: 100 feet (30 m)

Projector

FRAMES
are 10 times larger than a traditional motion-picture frame, providing better image definition.

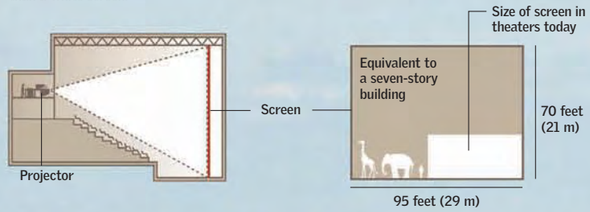
IMAX frame

Traditional 35-mm frame

Varieties

IMAX 3-D
Viewers must wear glasses that allow them to see in three dimensions.

FLAT IMAX
uses a silver-colored flat screen, which reflects projected light more strongly than a white screen.

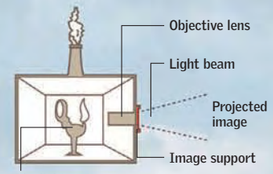


MOVIE SET
French director, screenwriter, and actress Nicole Garcia on the set of her movie *Every Other Weekend (Un Week-end sur deux)*.

The First Projection Systems

1400

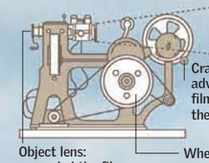
Roger Bacon invents the magic lantern, the first step toward the modern projector.



The light source was an oil lamp

1895

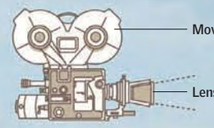
The Lumière brothers invent the first projector, inspired by a sewing machine, and hold a screening in Paris.



Object lens: expanded the film frame up to 35 x 24 inches (90 x 60 cm).

1932

Color movies appear. The Technicolor camera superimposes three films—red, blue, and green—to produce a color image.



Television

The origins of television date back to 1884, when Paul Nipkow invented a rotating scanning disk camera for capturing moving images, but it was only in 1936 when the first modern TV broadcast was made in England. The invention of radar during World War II reduced the costs of this technology, making it accessible to the general public. In spite of its slow beginning, television became an important medium for communication, greatly influencing the opinions, behaviors, and imagination of several generations. Today analog technology is being replaced by digital technology, and three-dimensional television is at the experimental stage.

1. TAPING

The camera captures images through its lens and sound through a microphone.

A VIDEO
The image is divided into a series of horizontal lines.

Each line is made up of points of different brightness. By convention, they are split into the three primary colors: **red**, **green**, and **blue**.

B SOUND
is codified and broadcast using the same method as the one employed in FM radio.

2. TRANSMISSION

Images and sound are transmitted together through radio, coaxial cable, or fiber-optic cable.
Each frequency is split between the image (AM) and the sound (FM).

VIA SATELLITE
Uses high-frequency radio waves. The signal can cover an entire country.

VIA AIRWAVES
Employs a system similar to AM and FM radio

VIA CABLE
A coaxial or fiber-optic cable permits the reception of a large number of channels.

3. RECEPTION

RECONSTRUCTING MOVEMENT

Each image is like a still photograph of a single moment.

American television broadcasts 30 frames per second at 60 hertz (60 times per second), while European television broadcasts 25 frames per second at 50 hertz.

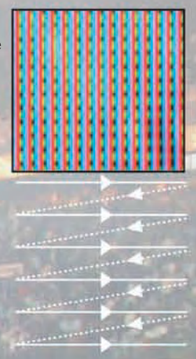
Each image correlates to an instant in time.

The images are integrated in the brain, resulting in the illusion of continuous movement.

RECONSTRUCTING THE IMAGE

Each image is shown twice. The 30 (25) frames per second are seen as 60 (50) fields per second.

In interlaced-format broadcasts, only half of the display lines of the image are swept with each field. One field delivers the odd-numbered lines, and the next delivers the even-numbered lines, and so on until the entire picture is drawn by interlaced scan.



The Printing Press

The social and cultural impact of the invention of the printing press is comparable to the development of language and the invention of the alphabet. It made possible the establishment of a scientific community, in which knowledge can be communicated with ease. In addition, it made the notion of authorship of a text more meaningful, the book became a popular object, and the dominance of Latin ended, definitively displaced by local tongues. According to some theorists, such as Marshall McLuhan, the press fostered the preeminence of words over the image, changing the way we understand the world today.

Digital Printing Systems

eliminate the need for film (used in traditional printing processes). These machines can accomplish all the steps of production up to delivery of the finished product. The development of the digital printing systems began in the 1990s.

1. INFORMATION INPUT
The information is sent from here. The original document is a digital file whose data is sent directly to the printer.

2. PAPER ENTRANCE

3. PRINTING
Ink is transferred to the paper. The machine is equipped with a rod that flips the paper over for two-sided printing (front and back).

4. CUTTING AND FOLDING
The printed spool of paper is cut, and the sheets are arranged so that the pages line up in proper order, including the cover.

5. BINDING AND FINISHING
The pages are stapled or glued together, and knife blades trim off the excess border to the publication's final size.

HEWLETT PACKARD INDIGO PRESS

PAPER ROLL

INKS

TURNING A FOLD

INTERNAL DENSITOMETER regulates how much ink is transferred.

PRINT DRUM

INKING SYSTEM

The printers use four basic ink colors to obtain the majority of colors. Special color inks (metallic, fluorescent, Pantone) can also be used.

Nondigital systems require a separate printing plate for each color, and each color is printed separately.

CYAN

MAGENTA

YELLOW

BLACK

Different Systems

These processes all require a printing plate or other printing surface but differ in the way they separate the printed area from the nonprinted area.

LETTERPRESS
The printing surface may be rigid or flexible.

FLEXOGRAPHY
The printing surface is flexible.

SERIGRAPHY
The printing surface is a mesh screen.

OFFSET
uses an aluminum printing plate covered with photosensitive material.

ROTOGRAVURE
The printing surface is a copper-coated cylinder with tiny pits, or cells, for the ink.

Technological Advances

593
In China, multiple copies of an image or text were made by carving wood.

Around 1450
MOVABLE TYPE
Johannes Gutenberg invented a printing system that used metal movable type. Words were assembled letter by letter and could be used to compose different pages.

Metal molds

1796
LITHOGRAPHY
Invented by Alois Senefelder in 1796, lithography is a printing method based on the property of immiscibility of ink and water.

1886
LINOTYPE
is similar to a typewriter. It allowed mechanized typesetting and composition, which until then had been a manual task.

1904
OFFSET
is a printing technique based on lithography that uses plates for the page surface. Currently offset is the most frequently used printing technique.

1990
DIGITAL
Computers eliminate the use of printing plates. Digital printing integrates all production steps in one single machine.

The Laser

Based on quantum mechanics, the laser is an optical device that emits a well-defined photon beam. The result is monochromatic light that can have various properties depending on the purpose for which it is designed. The name is an acronym for Light Amplification by Stimulated Emission of Radiation. When lasers were invented in 1960, they were called a "solution in search of a problem." They have since resolved myriad "problems" in the sciences, the arts, medicine, industry, and everyday life, becoming an essential tool in modern society.

THE INVENTOR
Theodore Maiman

Year **1960**
Type **Ruby laser**

It was the first working laser, and it was built using a ruby rod measuring just a few centimeters across.

THEORETICAL PRINCIPLES

A laser is based on the behavior of atoms, which are in constant motion and can achieve different states of excitation.

ATOM

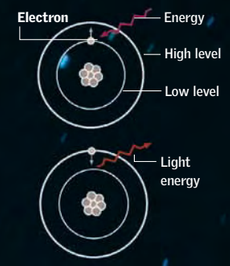
This generates different types of energy. External stimulation with heat, electricity, or light can result in the conversion of static energy to kinetic energy.

THE LASER LIGHT

is directed and has a predetermined wavelength. Its power resides in the concentration of photons within a narrow beam.

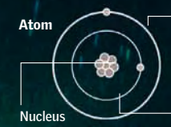
AN ELECTRON'S LEAP
LIGHT GENERATION

When an electron is struck with a burst of energy, it can momentarily jump to a higher-energy (outer) orbit.



When the electron returns to its original orbit, it releases energy in the form of a photon.

ORBITS AND THEIR ENERGY LEVELS



Outer orbit
Energy levels depend on the proximity of the orbits to the nucleus. The greater the distance, the higher the energy level.

Inner orbit
Low energy level

How a Beam Is Formed

Light is amplified by stimulated emission of radiation.

1 **The ruby rod is shown with its atoms at rest.**

2 **The light from the lamp stimulates the atoms.**

3 **Ordinary red light is emitted by the atoms.**

4 **Photons that are reflected in the interior stimulate other photons.**

5 **This process results in a cascade of photons.**

6 **The laser beam (photons) exits the rod with a uniform wavelength, which can be adjusted to produce beams of different colors.**

Total-reflection mirror

Atoms in the ruby rod

Quartz flash tube

Partially reflecting mirror

The inner surface of the cylinder is polished to reflect the dispersed light.

A few photons escape.

Most photons are reflected again.

Some photons are lost.

The light is composed of particles (photons) with a specific level of energy. The process by which photons propagate outward to form the laser beam is called radiation.

ELECTRIC LIGHT
The amount of light emitted by a small lamp is greater than the amount of light emitted by a laser, but the light does not have a specific wavelength and direction.

THE LASER IN ASTRONOMY
The Starfire Observatory in New Mexico uses an advanced laser system to stabilize star images, eliminating the twinkling effect.
Lasers are also used in astronomy to make measurements. In this way the distance from the Earth to the Moon was measured with great accuracy.

Laser light exists in nature. It is produced by the light of some stars that act on surrounding gases.

Holography

Based on the optical phenomenon of interference, holography is a photographic technique that allows an image to be recorded in three dimensions on a flat surface. Holograms are often confused with the transmission of three-dimensional images, particularly in science-fiction series and films, such as *Star Trek* or *Star Wars*. Holograms are commonly used as security features on credit cards, currency, and merchandise, because they are difficult to counterfeit. Holography is currently being researched as a way to protect digital data. One of the technologies in development uses high-density crystals to store the data. Another is the so-called Holographic Versatile Disc (HVD). ●

Principles

The creation of holographic images is based on the behavior of light through space, time, and wave interference.

If two or more wavefronts cross each other, interference is produced. The resulting wave incorporates the positive and negative amplitudes of the original waves.

THE INVENTOR
was born in Budapest, Hungary. He received the Nobel Prize for Physics in 1971.

DENNIS GABOR
1900-79

While conducting research to improve the resolution of the electron microscope, Gabor discovered a process that recorded and reproduced three-dimensional images. It was described in 1947, prior to the invention of the laser beam, and became known as holography.

Holographic Recording Process

1 The laser emits a beam.

2 The beam is split in two.

3 One of the two beams is reflected by a mirror and dispersed by means of a lens, thereby illuminating the object. The second beam is directed at another mirror.

4 A diverging beam illuminates the original object, which reflects part of the light toward the photosensitive plate.

5 The second beam is reflected by the second mirror, passes through a diverging lens, and illuminates the photosensitive plate.

6 When the two beams meet on the photosensitive plate, they produce a hologram or interference pattern. When the hologram is illuminated again by the reference beam, the original object image is re-created.

6,000

is the number of CD-ROMs needed to store the four terabytes contained in an HVD.

Science and Health

LASER EYE SURGERY
At one time considered a revolutionary technique, this technology has now become so commonplace and simple that it can even be performed at malls, with the public able to watch the procedure.

MAGNETIC RESONANCE IMAGING 54-55
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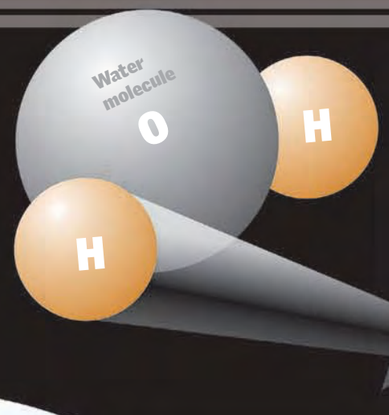
At one time, the practice of medicine was more of an artisan's craft than a science and involved just a few tools to cure people. Around 500 years ago, due to remarkable scientific and technical advances, medicine became a technological discipline. Because of this development, life expectancies increased significantly, and remedies that before might have been considered miraculous became commonplace. Obviously the story is not over yet, and there is still much to be accomplished, but advances, such as robotic surgery, where a doctor performs surgery remotely, or the use of magnetic resonance equipment that can detect tumors in soft tissue, are very important. ●

Magnetic Resonance Imaging (MRI)

Thanks to a sophisticated technology that combines magnetic fields and radio waves, it is possible to render high-quality images of soft tissue in the human body without inconvenience to the patient, other than the requirement for the patient to remain still for a few minutes. Another revolutionary feature of this technique is that it does not require the use of contrast agents or the use of X-rays, as is the case for radiography or computerized tomography.



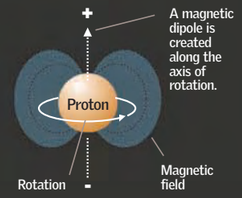
HYDROGEN IN THE BODY

Hydrogen atoms are present in almost all tissues and fluids, especially in water (which makes up 70 percent of the body) and in fat.

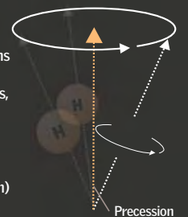
The hydrogen atom

is the simplest element of nature.
It has just one proton (+) and one electron (-).

Because of its physical structure, the hydrogen atom's proton spins on its axis. This generates a magnetic field that will interact with an external magnetic field.



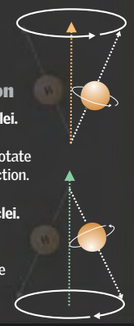
It also spins around a second axis, like a top, traveling within a conelike (precession) trajectory.



Classification

Low-energy nuclei. The spin and the precession axis rotate in the same direction.

High-energy nuclei. The spin and the precession axis rotate in opposite directions.



Inside a Scanner

To render an image of the soft tissue in the human body, the machine scans for the hydrogen atoms in these tissues. To detect the atoms, the area is initially subjected to a powerful magnetic field and later stimulated using radio-frequency waves. This process causes the atoms to release energy that is then detected by the scanner and converted into images.

Superconducting magnet

The magnet, made out of a niobium-titanium alloy, becomes a superconductor when it is cooled to -452° F (-269° C). It generates a powerful magnetic field that lines up the hydrogen protons prior to their being stimulated with the radio waves.

Cooling systems

In addition to compensating for the enormous amounts of heat generated by the electromagnetic equipment, these systems cool the main magnet to -452° F (-269° C) to turn it into a superconductor. Liquid helium is generally used as the cooling agent.

Magnetic gradient coils

generate secondary magnetic fields that, together with the superconducting magnet, enable imaging of different planes of the human body.

Radio-frequency transmitter

emits radio signals through a transmitting coil (antenna) to stimulate the hydrogen atoms that are aligned by the magnetic field. When the stimulation stops, the atoms release energy that is captured and used to form the image.

Planes

Magnetic resonance imaging can generate cross-sectional images at any point in the human body and in any plane.

Profile cross section

Frontal cross section

Top cross section

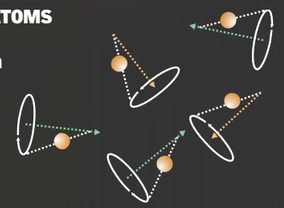
High Magnetism

The magnetic field generated by MRI scanners tends to be tens of thousands of times more powerful than the magnetic field of the Earth.

HUNTING FOR ATOMS

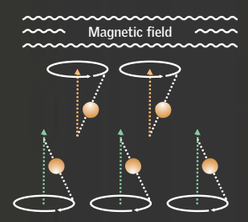
1 Hydrogen in the body

The axes of precession are randomly oriented in different directions.



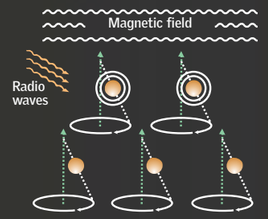
2 Magnetism

A strong magnetic field helps to line up the precession axes in the same direction.



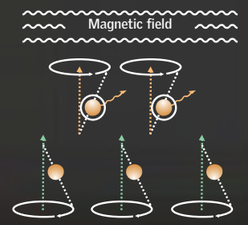
3 Stimulation

Next, energy in the form of radio waves is applied, and low-energy protons absorb it to become high-energy protons.



4 Relaxation

When transmission of radio waves stops, the low-energy protons return to their previous state. While they relax, they release the energy they have absorbed.



5 Analysis

This released energy is interpreted by the MRI scanner to form images.

Positron Emission Tomography (PET)

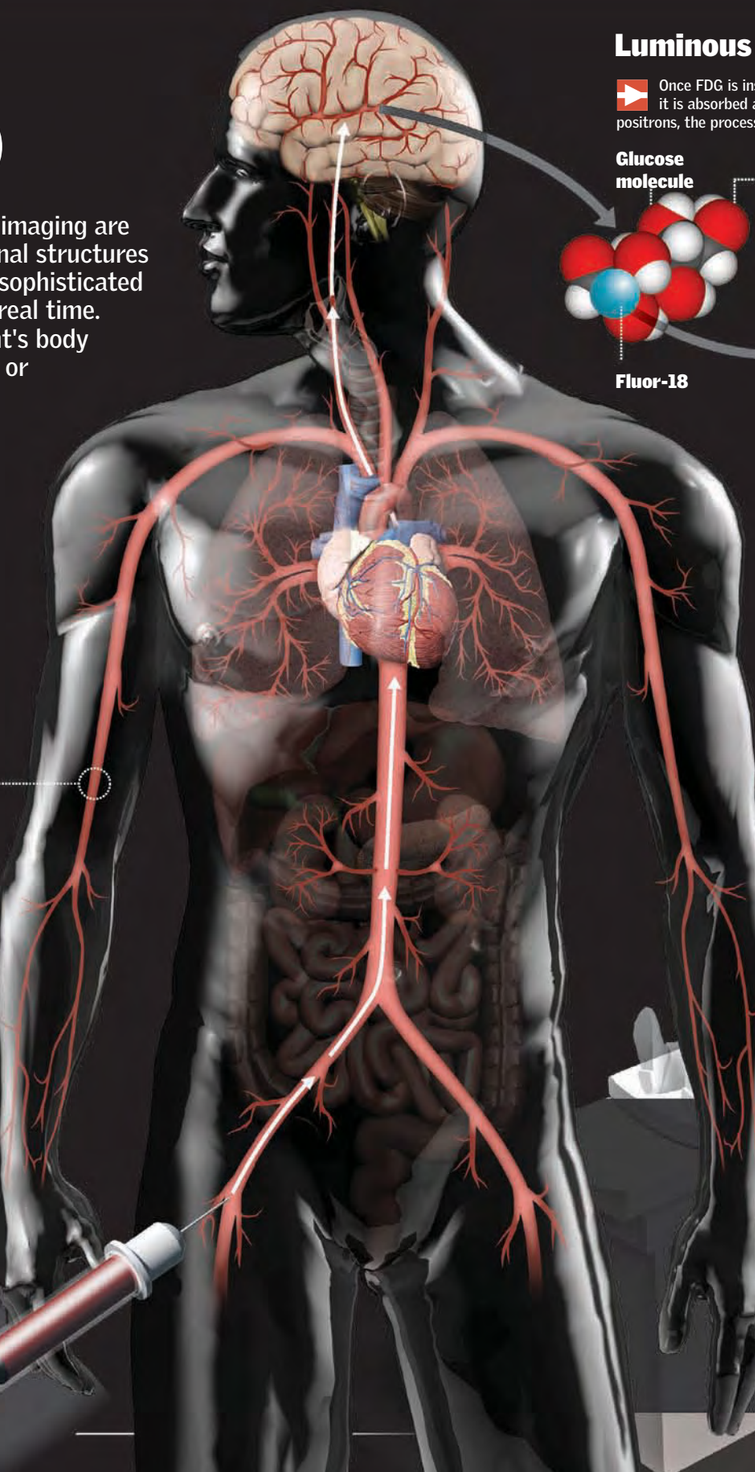
Just as computed tomography and magnetic resonance imaging are well-established diagnostic methods for studying internal structures of the body, PET has in recent years become the most sophisticated technique for studying biochemical processes in patients in real time. Specialists can use it to determine how tissues in the patient's body are working and thereby obtain precise diagnoses of cancer or neurological disorders, which are difficult to determine with other methods.

Glucose

is the main source of energy in cells. For this reason, the study of how glucose is being used in the body tells a great deal about metabolism. Anomalies in metabolism can be related to important diseases, such as malignant tumors and Alzheimer's disease.

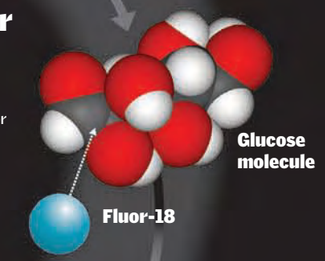
90%

The percentage of correct PET-derived diagnoses of cancer, including early-stage cancers



Following the Tracer

In order to study the behavior of glucose in the body, it is necessary to tag it with a tracer so that it can be detected. Glucose with a radioactive tracer is injected into the body for this purpose. It is metabolized like ordinary glucose and readily observable in a PET scan.



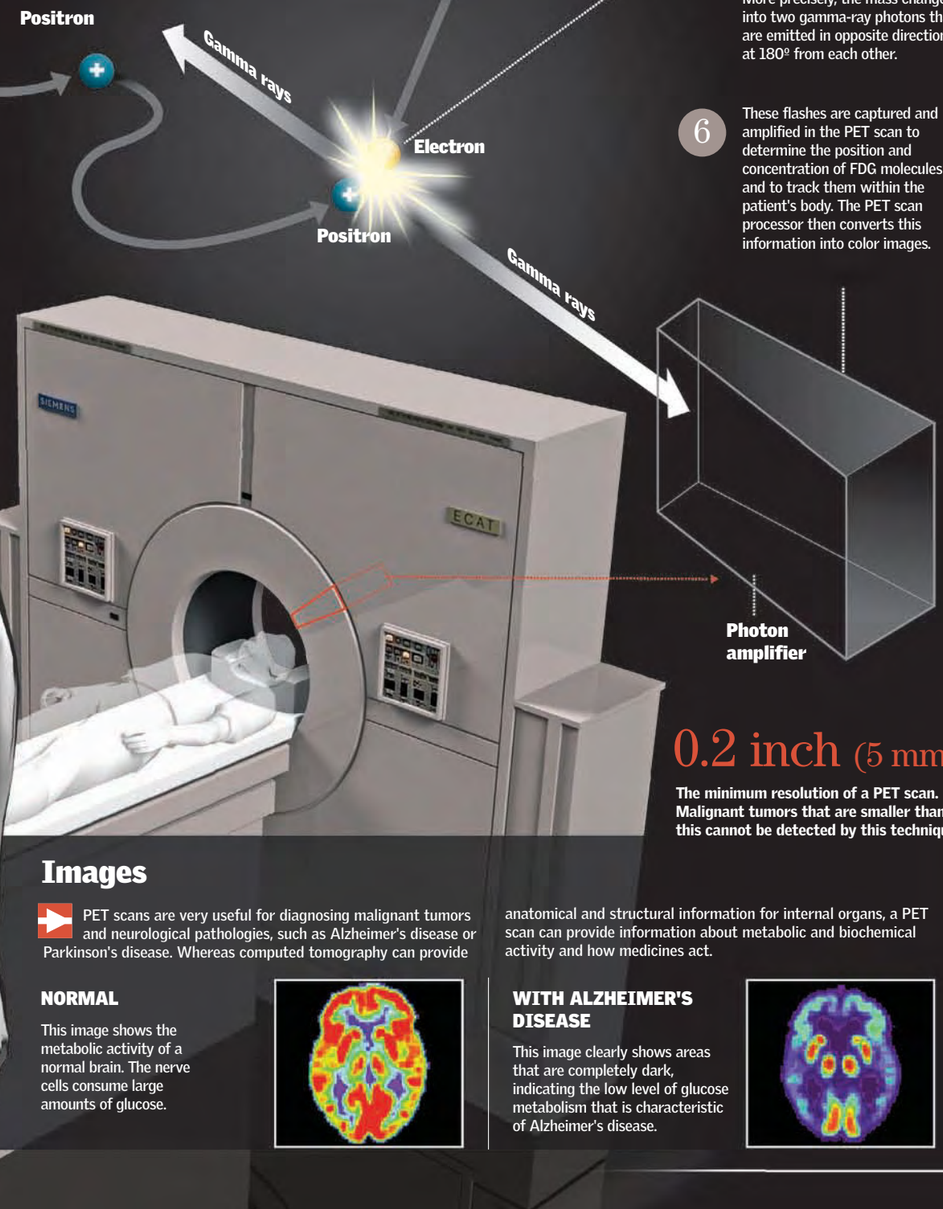
1. The glucose molecule is treated with a radioactive isotope (a type of unstable atom). Fluor-18 is typically used, though carbon-11, oxygen-15, and nitrogen-13 can also be used.

2. The radioactively tagged glucose (in this case fluorodeoxyglucose, or FDG) is injected in the patient under study.

Luminous Collision

Once FDG is inside the body of the patient, it emits positrons as it is absorbed and metabolized. Thanks to the emission of positrons, the process can be followed in a PET scan.

3. Within the FDG molecule, fluor-18 emits positrons, which are the antimatter equivalent of electrons. In other words, positrons are electrons that have a positive instead of a negative charge.



4. In the rest of the tissues and structures of the body, there are many free electrons that are susceptible to encountering positrons emitted by the FDG.

5. When an electron (with a negative charge) collides with a positron (with a positive charge), both particles are annihilated and all their mass changes into energy. More precisely, the mass changes into two gamma-ray photons that are emitted in opposite directions, at 180º from each other.

6. These flashes are captured and amplified in the PET scan to determine the position and concentration of FDG molecules and to track them within the patient's body. The PET scan processor then converts this information into color images.

0.2 inch (5 mm)

The minimum resolution of a PET scan. Malignant tumors that are smaller than this cannot be detected by this technique.

Images

PET scans are very useful for diagnosing malignant tumors and neurological pathologies, such as Alzheimer's disease or Parkinson's disease. Whereas computed tomography can provide anatomical and structural information for internal organs, a PET scan can provide information about metabolic and biochemical activity and how medicines act.

NORMAL

This image shows the metabolic activity of a normal brain. The nerve cells consume large amounts of glucose.

WITH ALZHEIMER'S DISEASE

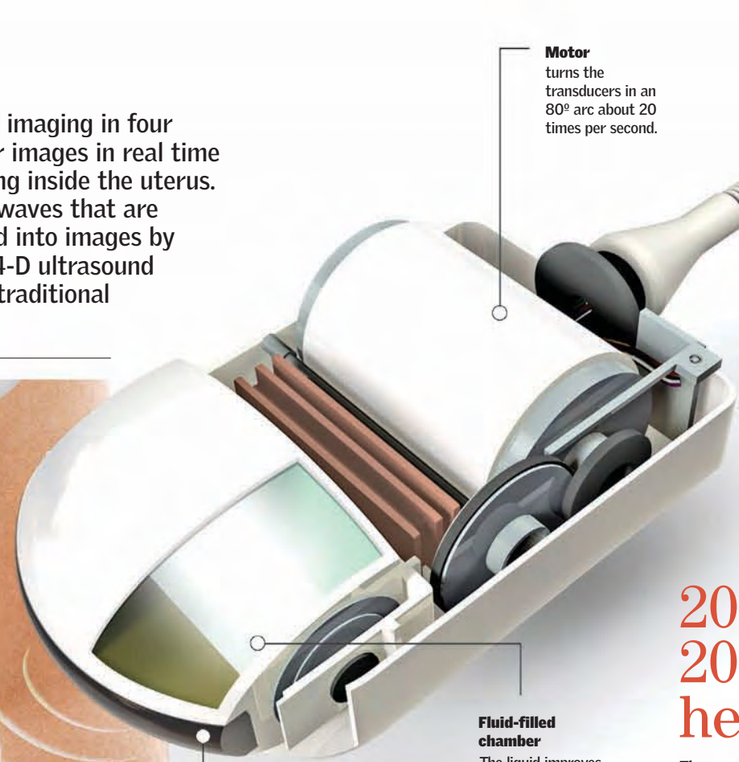
This image clearly shows areas that are completely dark, indicating the low level of glucose metabolism that is characteristic of Alzheimer's disease.

4-D Ultrasound

Is the latest word in diagnostic examinations in obstetrics. Ultrasound imaging in four dimensions incorporates time as a new variable, and it produces color images in real time that give the impression of watching a movie of a baby as it is growing inside the uterus. However, it is not a movie properly speaking but the sweep of ultrasonic waves that are reflected as echoes by the fetus. These echoes are analyzed and converted into images by powerful processors that perform mathematical calculations. The use of 4-D ultrasound has not yet been completely embraced by doctors, many of whom prefer traditional two-dimensional ultrasounds for their exams. ●

The Ultrasonic Window

The ultrasound machine uses a handheld probe that is moved over the mother's abdomen. The probe contains transducers that emit ultrasonic (high-frequency) waves that pass through the abdomen and bounce off the baby, creating echoes. These reflected waves are detected by the transducer and then converted into images.



Motor
turns the transducers in an 80º arc about 20 times per second.

Fluid-filled chamber
The liquid improves the efficiency of the transmission of ultrasonic sound waves.

Transducers
There are usually 128. They both emit ultrasound waves and also receive those waves that are reflected back.

5,000
The times per second that the transducer emits ultrasonic waves and detects the waves that are reflected by the fetus

20 to 20,000 hertz
The range of frequencies that humans can hear. Ultrasound imaging uses frequencies that range from 1,500,000 hertz to 60,000,000 hertz.

How It Works

Although the result of the exam is a moving image of a fetus in color, the ultrasound machine does not use optical equipment but only sound waves reflected by the baby. This imaging method is generally not considered to pose a risk for the fetus or the mother.

1 Emission
The transducer emits ultrasonic waves at specific frequencies that will pass through external tissues into the uterus where the baby is. A motor varies the plane of the emitted waves many times a second to produce three-dimensional images.

2 Echo
The ultrasonic waves collide with and bounce from fetal tissues. The frequencies used are inaudible to the human ear.

3 Reception
The transducer receives the waves reflected from the tissues of the fetus. Depending on their characteristics and how they were modified, the processor extracts information from the reflected waves and converts them into moving images in real time.

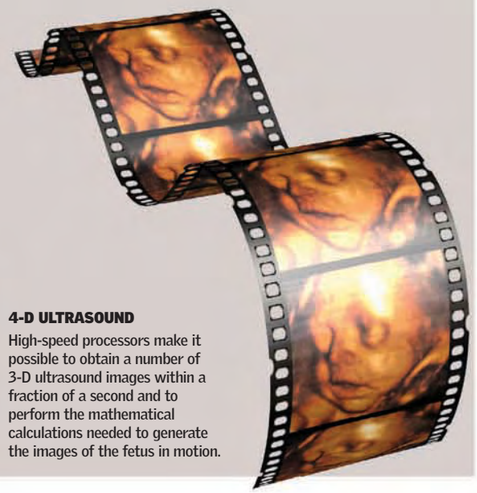
Development

Ultrasound imaging technology has developed in recent years from producing somewhat confusing multicolored pictures to movielike images of the fetus in the uterus.

2-D ULTRASOUND
is for obstetrics the ultrasound-imaging method par excellence. Although it is much less spectacular than more modern methods, doctors prefer it because it provides cross-sectional views of the fetus from any angle, which is helpful in examining its internal structures.

3-D ULTRASOUND
yields a static three-dimensional image of the fetus. It can be used to identify structural malformations and even facial features. The image is produced by obtaining a series of parallel cross-sectional views along the length of the fetus. These views are then processed mathematically to produce the three-dimensional image.

4-D ULTRASOUND
High-speed processors make it possible to obtain a number of 3-D ultrasound images within a fraction of a second and to perform the mathematical calculations needed to generate the images of the fetus in motion.

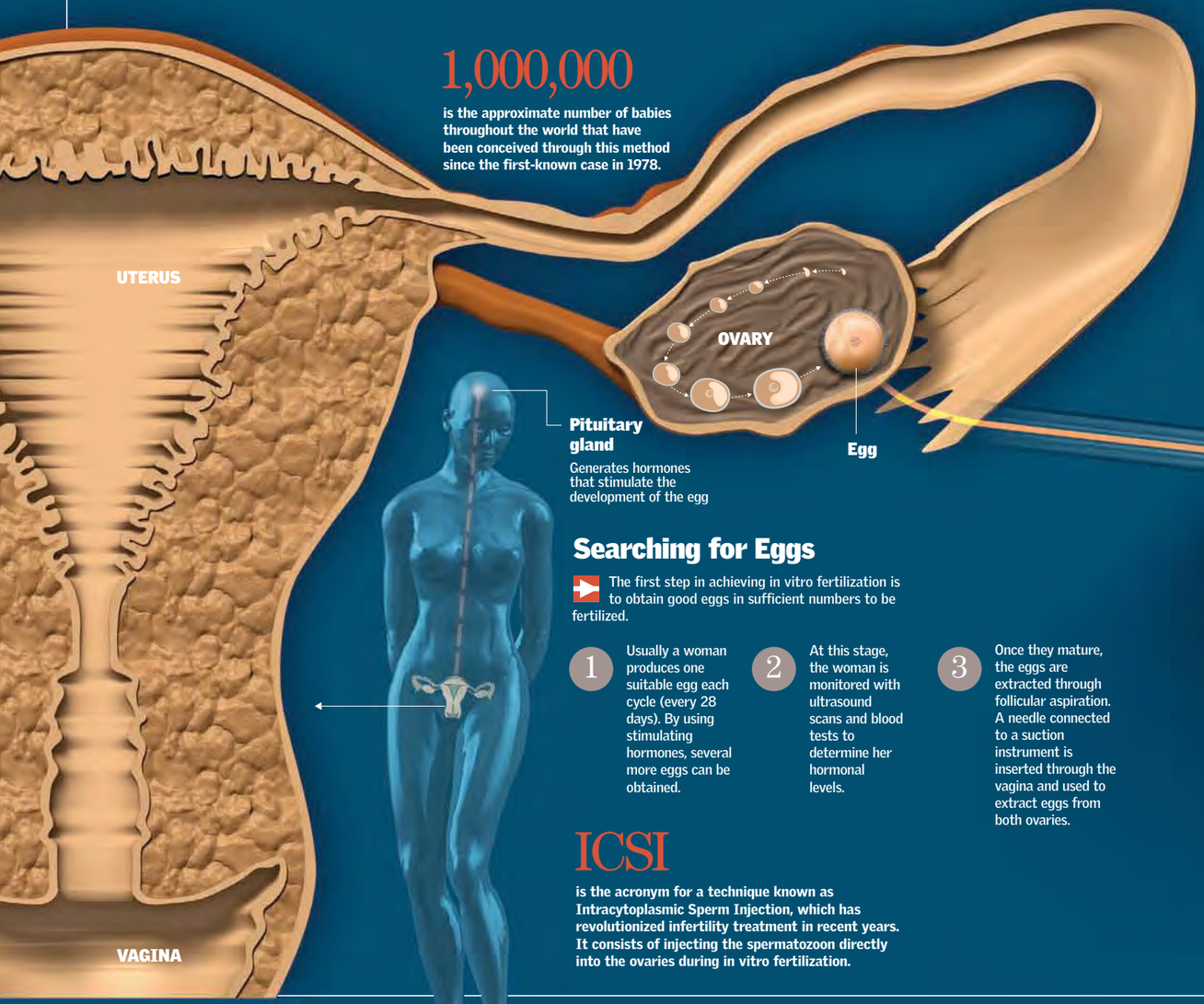


In Vitro Fertilization

Ever since the first successful case of in vitro fertilization in the United Kingdom almost three decades ago, this technique has become the most popular and widespread method of assisted reproductive technology. It involves removing a woman's ova, or eggs, and fertilizing them with sperm outside the woman's womb; in fact, the procedure is done in a laboratory to avoid various problems that can hinder a natural pregnancy. Once fertilized, the embryo is implanted in the uterus to continue gestation. Over time, in vitro fertilization techniques have become more efficient, and in the past few years, the number of successful pregnancies has seen a seven-fold increase. Today in vitro fertilization can be combined with other techniques to increase the chances of conception.

1,000,000

is the approximate number of babies throughout the world that have been conceived through this method since the first-known case in 1978.



Searching for Eggs

The first step in achieving in vitro fertilization is to obtain good eggs in sufficient numbers to be fertilized.

1. Usually a woman produces one suitable egg each cycle (every 28 days). By using stimulating hormones, several more eggs can be obtained.
2. At this stage, the woman is monitored with ultrasound scans and blood tests to determine her hormonal levels.
3. Once they mature, the eggs are extracted through follicular aspiration. A needle connected to a suction instrument is inserted through the vagina and used to extract eggs from both ovaries.

ICSI

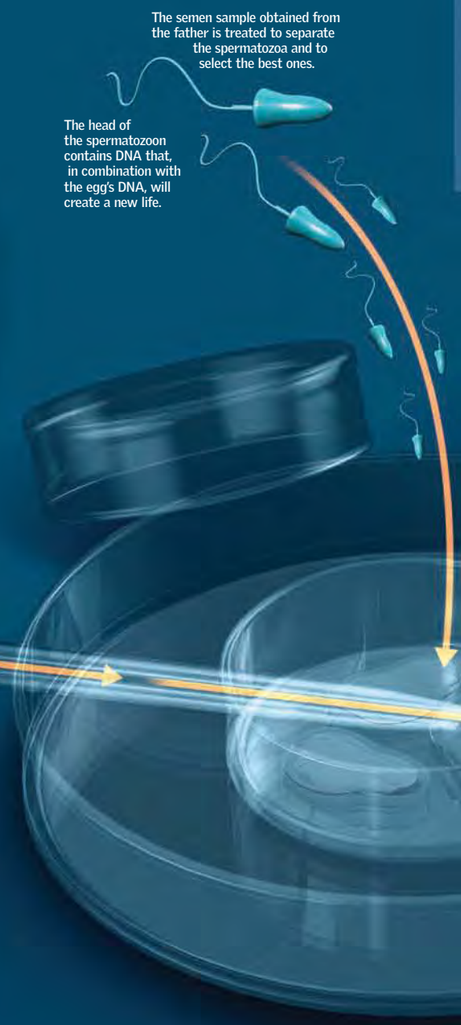
is the acronym for a technique known as Intracytoplasmic Sperm Injection, which has revolutionized infertility treatment in recent years. It consists of injecting the spermatozoon directly into the ovaries during in vitro fertilization.

A Baby Factory

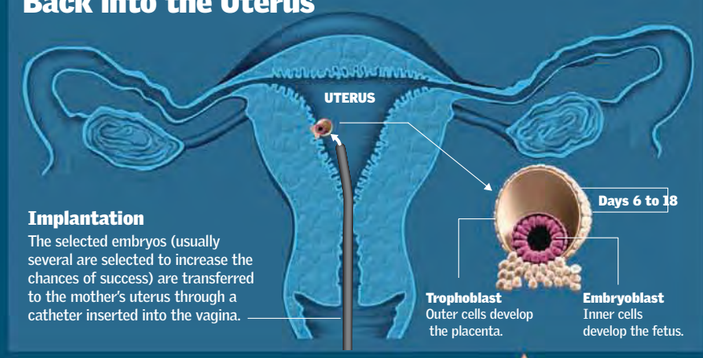
Once the most suitable eggs are selected, they are fertilized in a laboratory with the sperm of the future father and either inserted into the mother's uterus or frozen for use at a later time.

The semen sample obtained from the father is treated to separate the spermatozoa and to select the best ones.

The head of the spermatozoon contains DNA that, in combination with the egg's DNA, will create a new life.



Back into the Uterus



Implantation
The selected embryos (usually several are selected to increase the chances of success) are transferred to the mother's uterus through a catheter inserted into the vagina.

Fertilization
takes place in a special cultivation medium in a petri dish at the same temperature as the human body.

The embryo
From this moment, the embryo is monitored and cared for by medical personnel. If it develops successfully, it will become a baby.

After 12 hours
the first cellular division takes place. The embryo now consists of two cells. The number of cells increases exponentially every 12 to 15 hours.

Day 3
When the embryo reaches between 16 and 64 cells, it is called a morula (from the Latin word *morus*, meaning "mulberry").

Day 5
When it surpasses 64 cells, the embryo becomes a blastula. A large cavity forms in the middle. At this phase, the embryo can be transferred to the woman's uterus.

Success Rates

of in vitro fertilization are determined by different factors, including the age of a patient's eggs.

For a 35-year-old woman, statistics show that only one of every 16 eggs will develop and result in a pregnancy.

Five eggs are not suitable.

Five eggs will not be fertilized.

Between one and six implanted eggs could produce a baby.

Bionic Implants

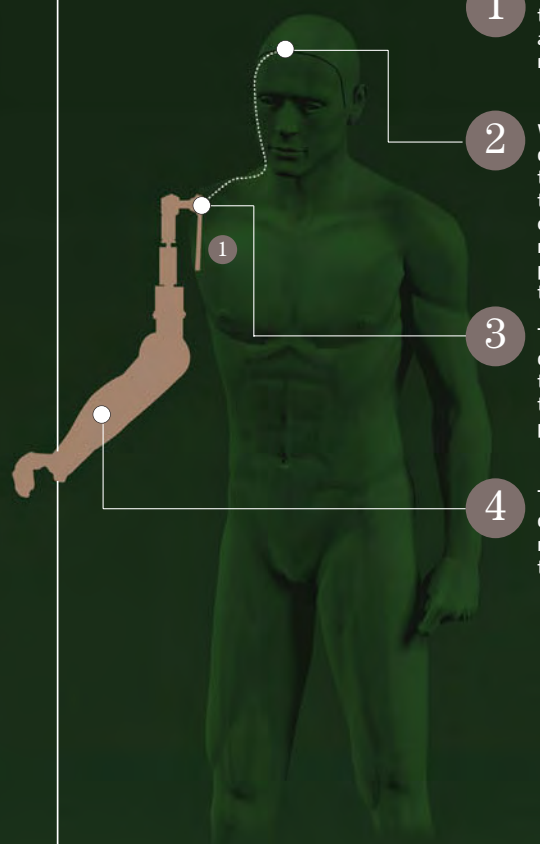
Until a few decades ago, the only option for amputees was the use of rigid and uncomfortable wood prostheses. Today at the beginning of the 21st century, the dream of being able to use artificial limbs that are connected through the nervous system—with the capability of responding to direct commands from the brain—is at the point of becoming reality. At least there are very advanced experimental prototypes along those lines, and there are already commercially available prostheses with surprising features, which in some cases are superior to human limbs.

Half Human, Half Machine

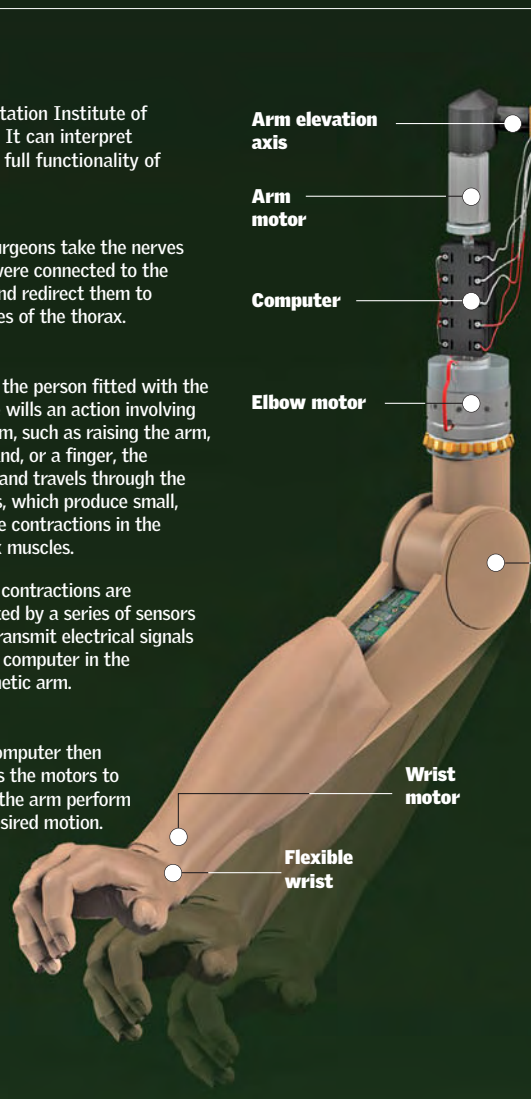
Among the numerous advances forthcoming in the next few years, in addition to bionic arms and legs, are: products stemming from the development of artificial veins, arteries, organs, and muscles; eyes and ears for the blind and deaf; microprocessors that enable quadriplegics to recover the use of their limbs; and even a device to eliminate chronic pain.

Almost Science Fiction

The experimental bionic arm developed by the Rehabilitation Institute of Chicago is one of the most advanced models yet made. It can interpret commands from the brain so that the patient can regain the full functionality of the limb that was lost.

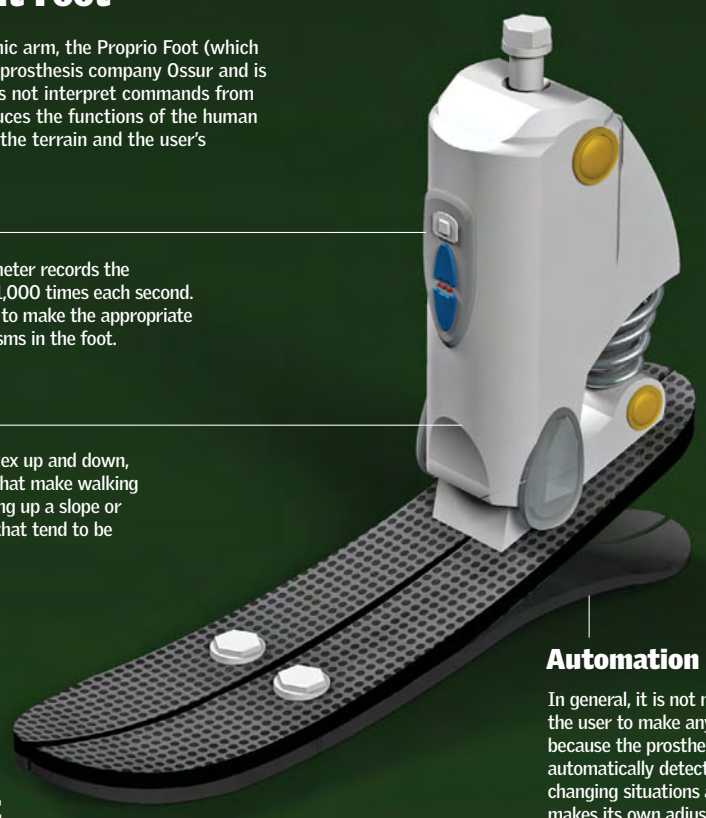


1. The surgeons take the nerves that were connected to the arm and redirect them to muscles of the thorax.
2. When the person fitted with the device wills an action involving the arm, such as raising the arm, the hand, or a finger, the command travels through the nerves, which produce small, precise contractions in the thorax muscles.
3. These contractions are detected by a series of sensors that transmit electrical signals to the computer in the prosthetic arm.
4. The computer then directs the motors to make the arm perform the desired motion.



The Intelligent Foot

In contrast to the bionic arm, the Proprio Foot (which was developed by the prosthesis company Ossur and is commercially available) does not interpret commands from the brain. Instead it reproduces the functions of the human foot by taking into account the terrain and the user's movements and gait.



Operation

A device called an accelerometer records the movement of the leg about 1,000 times each second. The computer uses the data to make the appropriate adjustments of the mechanisms in the foot.

Versatility

The Proprio Foot can turn, flex up and down, and carry out adjustments that make walking comfortable, even when going up a slope or climbing stairs—situations that tend to be difficult for amputees.

Automation

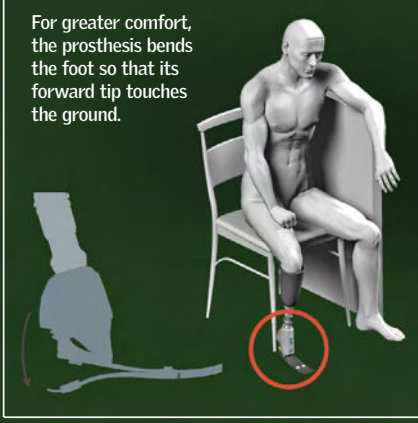
In general, it is not necessary for the user to make any adjustments because the prosthesis automatically detects and analyzes changing situations and continually makes its own adjustments.

Always Alert

The Proprio Foot responds, without input from the user, to such situations as being seated in a chair or going up or down stairs.

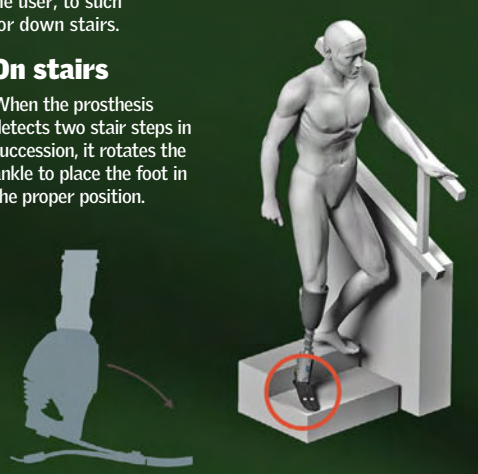
Sitting

For greater comfort, the prosthesis bends the foot so that its forward tip touches the ground.



On stairs

When the prosthesis detects two stair steps in succession, it rotates the ankle to place the foot in the proper position.



600 million

The number of persons worldwide who have some type of disability. The figure accounts for 10 percent of the world population.

Robotic Surgery

The use of robots to perform surgeries stopped being a science-fiction fantasy and became a reality about 10 years ago, when the first surgeries of this kind were performed. During unassisted robotic surgery, the surgeon works from a computer console while a robot with special arms operates directly on the patient. This type of surgery enables the surgeon to operate remotely on patients located across the world by using a high-bandwidth connection. Robotic surgery offers numerous advantages, such as extreme precision of the incisions (hand movements are scaled and filtered to eliminate hand tremors) and the small size of incisions, which shortens recovery time for the patient and allows a given doctor to operate on a specific patient without having to be in the same physical location.

The Console

is where the surgeon performs the surgical procedure. The virtual-reality environment allows the doctor to observe incisions and organs magnified up to 20 times.

In spite of not operating on a patient directly, the console allows the doctor to "feel" the operation, because the robot transmits data related to flexibility, pressure, and resistance, among other information.

500,000

is the approximate number of robotic surgical procedures that have been performed since the technique was first developed in 1977.

The Robot

obeys the surgeon's instructions sent from the console. Its arms have ample freedom of movement and hold the surgical instruments used to perform the operation.

The robot filters out the surgeon's abrupt movements or hand tremors, making the surgery more efficient.

The various surgical instruments used at different stages during the operation are easily replaced.

The necessary incision for each instrument used in the operation measures less than the radius of a pencil.

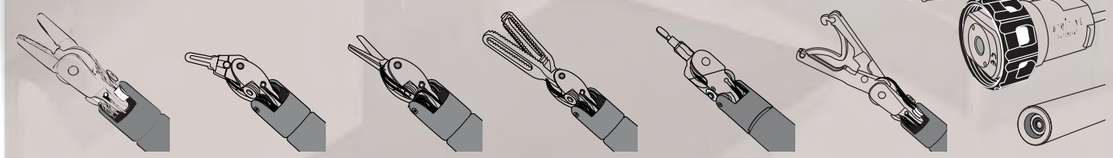
During robotic surgical procedures, a doctor or nurse assists the surgeon.

2,200

is the number of robotic surgeons currently practicing around the world.

Special Surgical Instruments

The robotic arms can hold a wide range of instruments, from scalpels of various sizes and cameras to suture materials, clamps, needles, and scissors.



Suture clamps · Scalpels · Scissors · Forceps · Cauterizers · Clip applicators · Cameras

Artificial Heart

The artificial heart has experienced a notable development since the first permanent artificial-heart implant in 1982, although the procedure continues to undergo experimental study because of its complexity. The most advanced artificial heart, a model called AbioCor, has been successfully implanted into a number of seriously ill heart patients, one of whom lived as long as 17 months with the device. The AbioCor heart is self-contained within the body and needs minimum maintenance. The marvel of the artificial heart is closer to becoming an everyday reality, although in the short term it is still not available for widespread use.

The Implant

is carried out while maintaining blood circulation by means of connections to the principal veins and arteries without using internal sutures that could hinder blood flow. The implant is a major surgical intervention.

Aorta artery
The oxygenated blood is pumped out of the heart through the aorta to the entire body.

Pulmonary artery
The heart pumps deoxygenated blood through the pulmonary artery to the lungs, where the blood is cleaned and oxygenated.

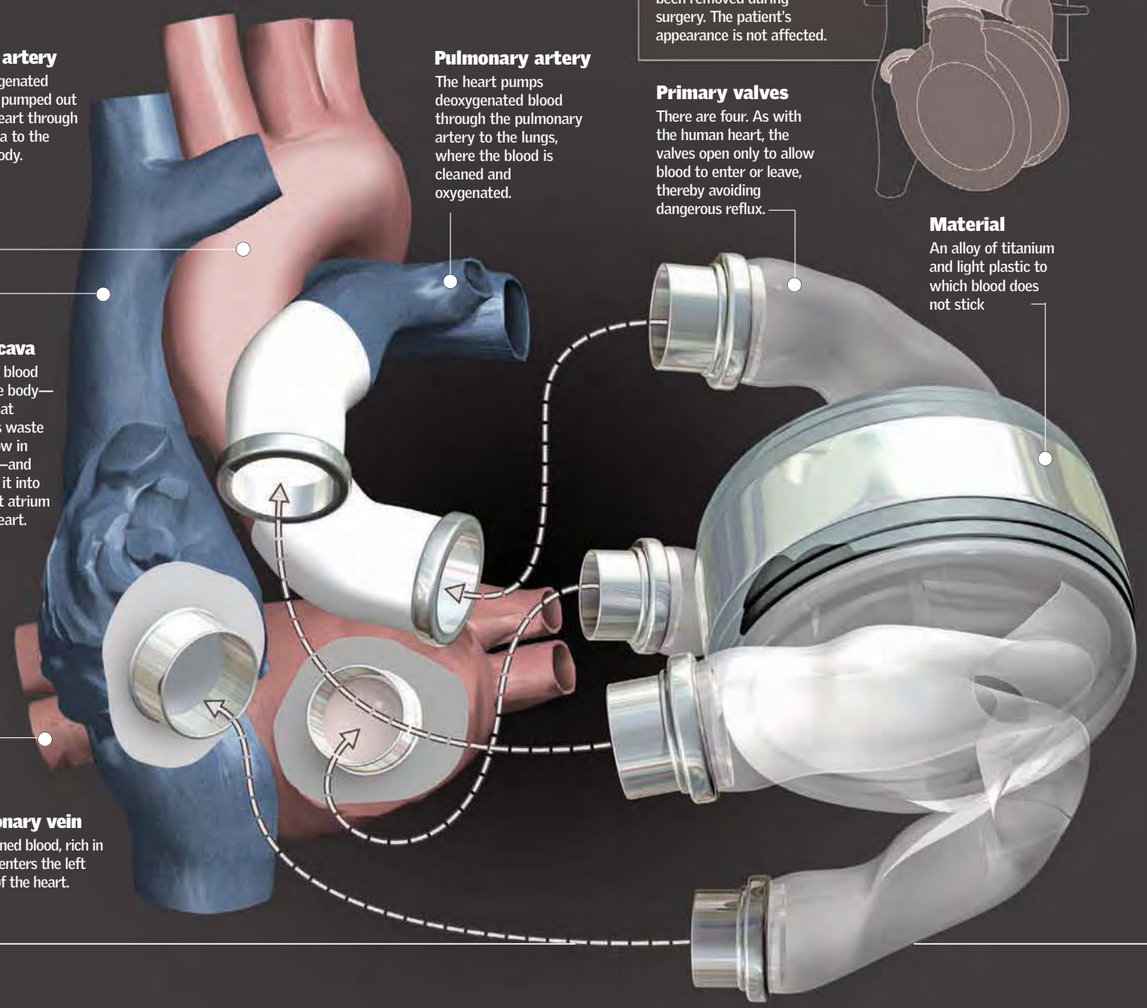
Vena cava
receives blood from the body—blood that contains waste and is low in oxygen—and empties it into the right atrium of the heart.

Pulmonary vein
The cleaned blood, rich in oxygen, enters the left atrium of the heart.

Location
The artificial heart occupies the cavity that remains after the patient's heart has been removed during surgery. The patient's appearance is not affected.

Primary valves
There are four. As with the human heart, the valves open only to allow blood to enter or leave, thereby avoiding dangerous reflux.

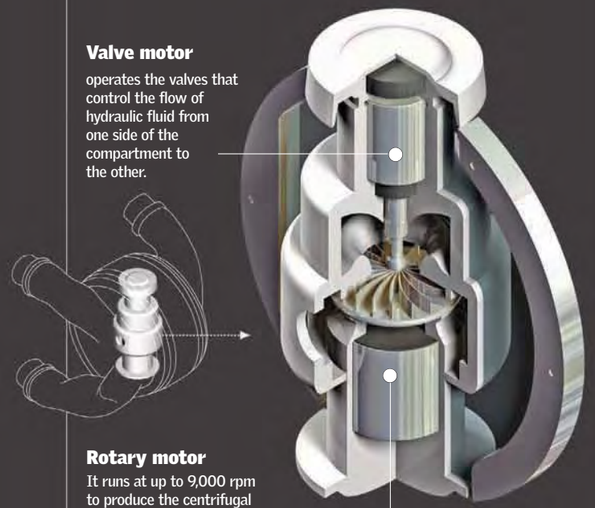
Material
An alloy of titanium and light plastic to which blood does not stick



How It Works

The key to the artificial heart is a compartment that has flexible walls and is filled with silicone fluid. An internal rotary motor causes the fluid to press outward, creating pressure against the flexible walls of the compartment. Valves direct this pressure, which is the secret to the proper operation of the artificial organ.

Valve motor
operates the valves that control the flow of hydraulic fluid from one side of the compartment to the other.

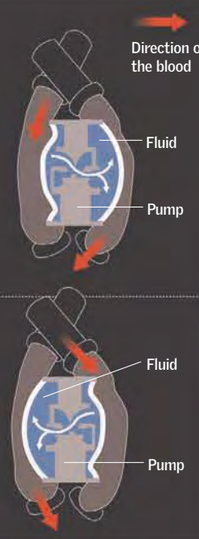


Rotary motor
It runs at up to 9,000 rpm to produce the centrifugal force that creates the hydraulic pressure.

PUMPING

1 The hydraulic pressure in the pump is directed against the flexible wall on one side of the pump. The wall pushes outward against an overlying chamber filled with blood and pushes the blood out of it. Meanwhile, the overlying chamber on the opposite side of the pump fills with blood.

2 The closed valves open and the open valves close, and the hydraulic pressure is shifted to the other side of the pump. The process repeats itself over and over.

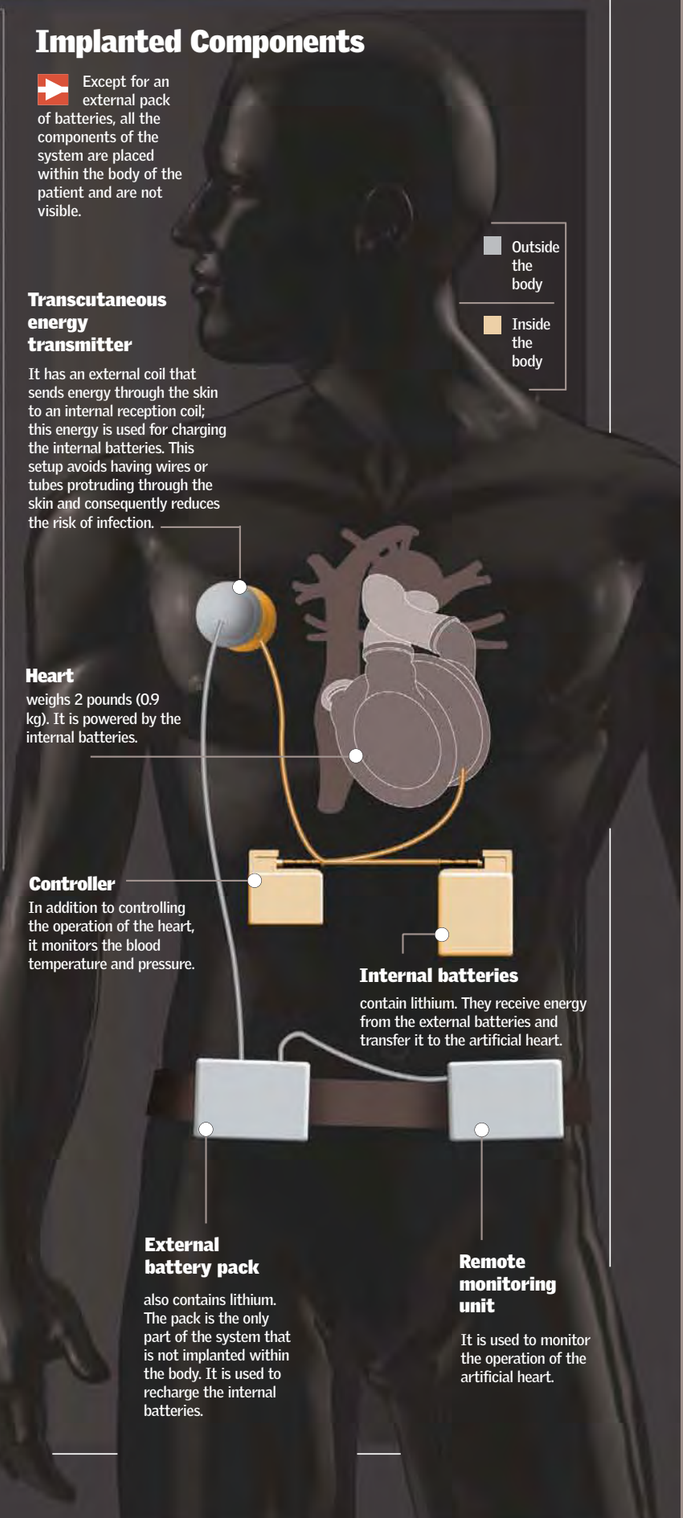


5 years

is the anticipated survival period for patients who, in a few years, will receive the AbioCor II, a new model whose introduction is expected in 2008.

Implanted Components

Except for an external pack of batteries, all the components of the system are placed within the body of the patient and are not visible.



Transcutaneous energy transmitter
It has an external coil that sends energy through the skin to an internal reception coil; this energy is used for charging the internal batteries. This setup avoids having wires or tubes protruding through the skin and consequently reduces the risk of infection.

Heart
weighs 2 pounds (0.9 kg). It is powered by the internal batteries.

Controller
In addition to controlling the operation of the heart, it monitors the blood temperature and pressure.

Internal batteries
contain lithium. They receive energy from the external batteries and transfer it to the artificial heart.

External battery pack
also contains lithium. The pack is the only part of the system that is not implanted within the body. It is used to recharge the internal batteries.

Remote monitoring unit
It is used to monitor the operation of the artificial heart.

Cutting-Edge Technology

ROBOT PRODUCTION
In the future, these machines will be able to "see," which will allow them to control airports, fly planes, and drive military vehicles.

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Today technology continues to pave the way toward the future and is beginning to change our lives and habits. Recently a number of documentaries have shown us different applications of smart technologies, technologies that are already in use in Japan, including companion robots that many families consider to be a family member. These types of technological breakthroughs are only now taking off, and they still tantalize and delight us. But one thing is certain: the future is here, and we are seeing it develop in front of our own eyes. We invite you to discover the numerous applications of nanotechnology and smart clothing, new allies in the search for a higher quality of life.●

Smart Houses

The goal of smart-house technology is to develop ways that give a house intelligence so that it can adapt on its own to the needs and wishes of the people who live in it while it also takes care of all the tasks related to home maintenance and security. Even though much of the technology that has been developed for this purpose is too expensive for most people, the continual advances made in this field suggest that in the near future almost all homes will have smart-house devices.

Watering the garden
The schedule for watering can be programmed to vary according to the season.

Central system
Central computer
Networked computer
Networked computer
Video
Alarm
Surveillance
Leaks
Lights
Entry points
Laundry and kitchen
Audio and video
Temperature

Remote connection
The house systems can be monitored from a computer or cell phone with an Internet connection.

Pool maintenance

Window blinds
can be programmed to open or close depending on the amount of sunlight.

Virtual paintings
use photographic images that are downloaded from the Internet and changed periodically.

Occupied-home simulator
When the house is empty for an extended period of time, the system opens blinds and turns on lights and appliances to make it appear that someone is at home.

Light sensors
measure the amount of natural light so that outdoor lighting can be used efficiently.

Water-leak detector

Appliance control
All the home appliances can be programmed and monitored from the central system.

Gas and smoke detector

Control for air conditioner

Computer
It can be used to monitor the system from any room of the house.

Antenna for satellite TV or Internet
An Internet connection can be used to control the system remotely.

Power-failure detector
Turns on emergency lighting

Sensors to detect open doors and windows

Video camera
A video system monitors the access points to the house.

Emergency lighting

Mail detector

Primary Functions

SECURITY SURVEILLANCE
- sounds an alarm when a house intruder is detected.

SECURITY PROTECTION
- warns of such dangers as fire, water or gas leaks, and electrical faults.

COMFORT AND ECONOMY
- systems to make the home comfortable and to use energy efficiently.

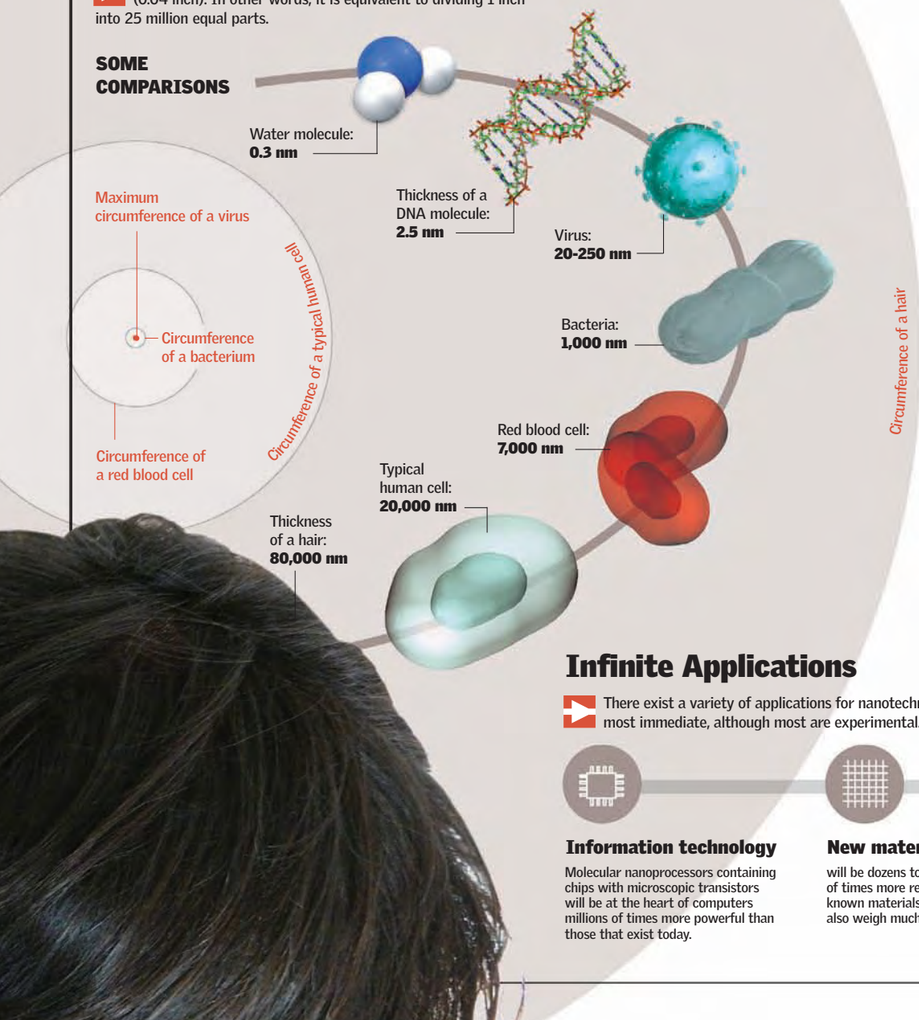
Nanotechnology

The term "nanotechnology" refers to the study, design, synthesis, manipulation, and application of materials, devices, and functional systems by controlling matter at the nanoscale. These new, atomically precise structures, such as carbon nanotubes or minuscule instruments to examine the inside of the human body, promise a new technological revolution still difficult to imagine. Specialists in the field expect numerous industrial, scientific, and social breakthroughs. One day, there will be materials that are more resistant than steel yet lighter, cleaner, and more efficient. Among many possible applications that could appear are computers with significantly faster components and molecular sensors capable of detecting and destroying cancer cells in the brain.

1 nanometer (nm)

is one-billionth of a meter, or one-millionth of a millimeter (0.04 inch). In other words, it is equivalent to dividing 1 inch into 25 million equal parts.

SOME COMPARISONS



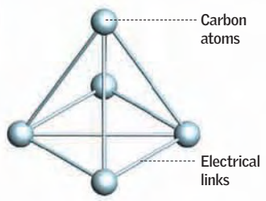
Challenges

One of the challenges researchers face is how to develop nanotubes of the longest possible length. The longest nanotube to date measures 1.5 inches (4 cm).

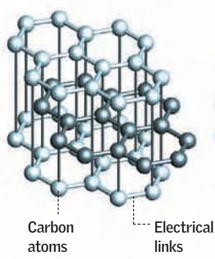
The Crystalline Structure

The structure formed by atoms once they align affects the properties of the material. One example is pure carbon, which, according to its structure, can become:

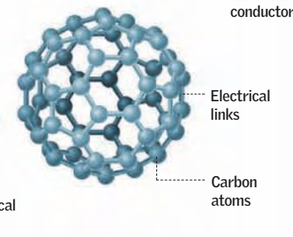
1 Diamond
Very hard, transparent mineral



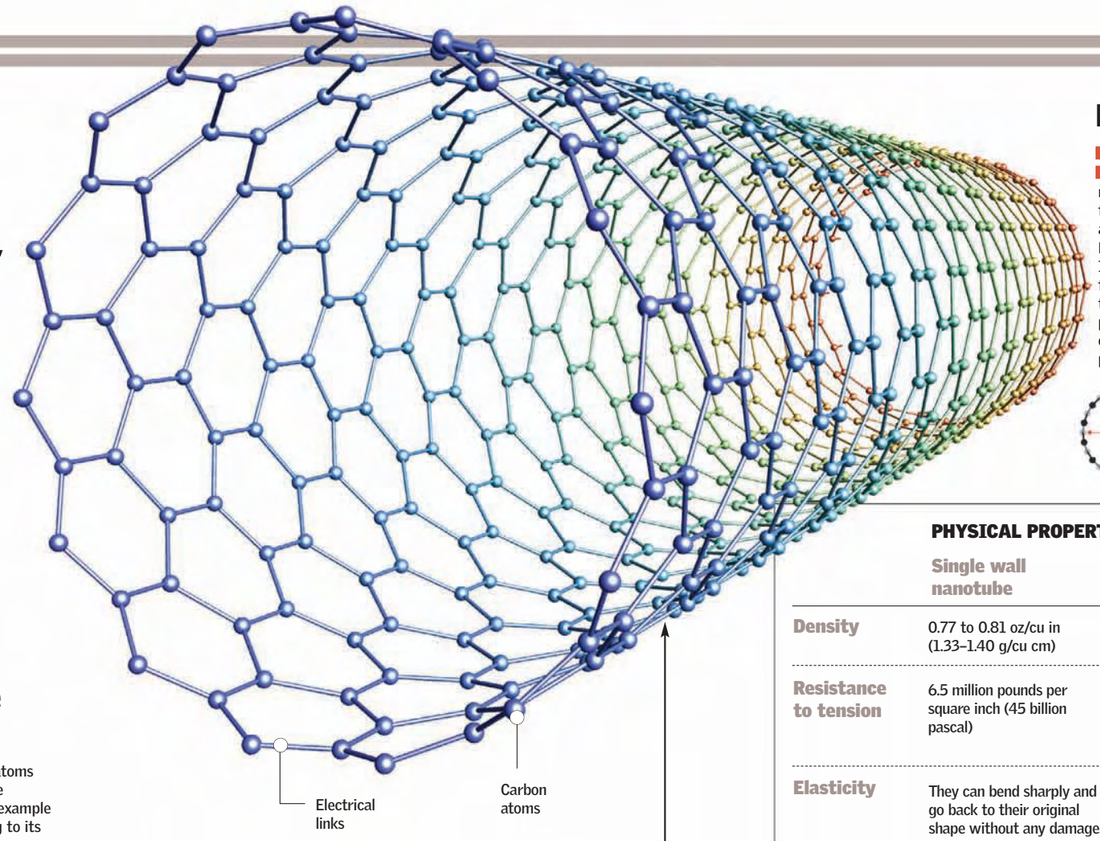
2 Graphite
Soft, scaly, and greasy



3 Fullerenes
A new material with unknown properties



4 Nanotubes
More resistant than steel and excellent electrical conductors



Nanotubes

are currently the stars of the field of nanotechnology. A nanotube is simply an atom layer folded into a tubelike shape one or a few nanometers in diameter. Nanotubes were discovered in 1991 and have several surprising features, such as the ability to give them metallic or semiconductor properties of electrical conductivity, among other properties currently under study.

Size
0.6 to 1.8 nanometers in diameter

PHYSICAL PROPERTIES

	Single wall nanotube	A comparison
Density	0.77 to 0.81 oz/cu in (1.33–1.40 g/cu cm)	Aluminum has a density of 1.6 oz/cu in (2.7 g/cu cm)
Resistance to tension	6.5 million pounds per square inch (45 billion pascal)	Very tough steel alloys break at around 290,000 pounds per square inch (2 billion pascal).
Elasticity	They can bend sharply and go back to their original shape without any damage.	Metals and carbon fibers break when subjected to similar tests.
Electric current capacity	Estimated at 6.5 billion amperes per square inch (1 billion/sq cm).	Copper wires melt at approximately 6.5 million amperes per square inch (1 million/sq cm).
Field emission	Can activate phosphates with 1 to 3 volts if the electrodes are spaced out at 0.00004 inch (1 μm).	Tips of molybdenum require fields of 15 to 30 volts per foot (50–100 V/m) and have very short life spans.
Heat transmission	It is predicted to be as high as 3,300 watts per foot per degree Fahrenheit (6,000 W/m/K) at room temperature.	An almost pure diamond transmits 1,800 watts per foot per degree Fahrenheit (3,320 W/m/K).
Thermal stability	Stable even at 5,100° F (2,800° C) in a vacuum environment and at 1,390° F (750° C) in the air.	The electrical wires inside microchips melt at between 1,100° F (600° C) and 1,800° F (1,000° C).

Infinite Applications

There exist a variety of applications for nanotechnology. The following examples are the most immediate, although most are experimental. The imagination is the only limit.

Information technology
Molecular nanoprocessors containing chips with microscopic transistors will be at the heart of computers millions of times more powerful than those that exist today.

New materials
will be dozens to hundreds of times more resistant than known materials but will also weigh much less.

Robotics
Microscopic robots (nanobots) will, for example, be able to travel inside organs and blood vessels to perform diagnostic tests and repairs.

Cosmetics
New smart creams, particularly highly efficient sunblocks

Transmission of electrical energy
Superconducting materials that do not suffer a loss of energy during transportation at room temperature

Medicine
New medicines. Molecular and genetic repairs. Microscopic, protein-building machines, among others.

Clothing
Highly resistant, intelligent fabrics that do not get dirty or that can repel viruses and bacteria

Solar energy
Huge improvements in maximizing this clean and inexhaustible energy source

Data storage
There already exists a memory card that measures just 0.005 square inch (3 sq mm) and has a capacity of 100 gigabytes.

Smart Clothing

With the invention of smart fabrics and computerized apparel, our clothing will undergo in the coming years one of the most dramatic and surprising evolutions since humans first began wearing clothes. Some of these new breakthroughs already exist: they are showing up for the first time in the market and are becoming readily available for mass consumption. Among them are materials that integrate features that would have been hard to imagine just a few years ago-for example, clothing that not only informs the wearer of the body's response to physical activity but also modifies itself to improve performance.

Smart Fabrics

Generally a product of new developments in nanotechnology, smart fabrics show surprising features that will be widely used in the next few years.

Colorful

A special fiber made of plastic and glass can be used with electronic circuitry that modifies the way the fabric reflects light and thereby changes color.

Comfortable

Fabrics that eliminate sweat, keep the skin dry, and eliminate odors already exist. Similarly, there are materials that can provide ventilation or warmth in accordance with the outside temperature.

Resistant

Fabrics that do not get wrinkled, are resistant to stain, and keep their shape after many years of wear and washing have also been developed.

Antistatic

Fabrics that remove static electricity. They prevent the buildup of hair, pollen, dust, and other potentially harmful particles for people with allergies.

Antimicrobial

Fabrics that block the growth of viruses, fungi, bacteria, and germs

INFORMATION IN REAL TIME

Clothes made out of fabrics with integrated minisensors and imperceptible electrical circuits can determine the wearer's heart rate, blood levels of oxygen and other gases, calories consumed, and breathing rate.

Diverse Users

Smart apparel is obviously of great benefit to athletes, but it is also important to patients with chronic illnesses, such as diabetics, who need to monitor their condition frequently.

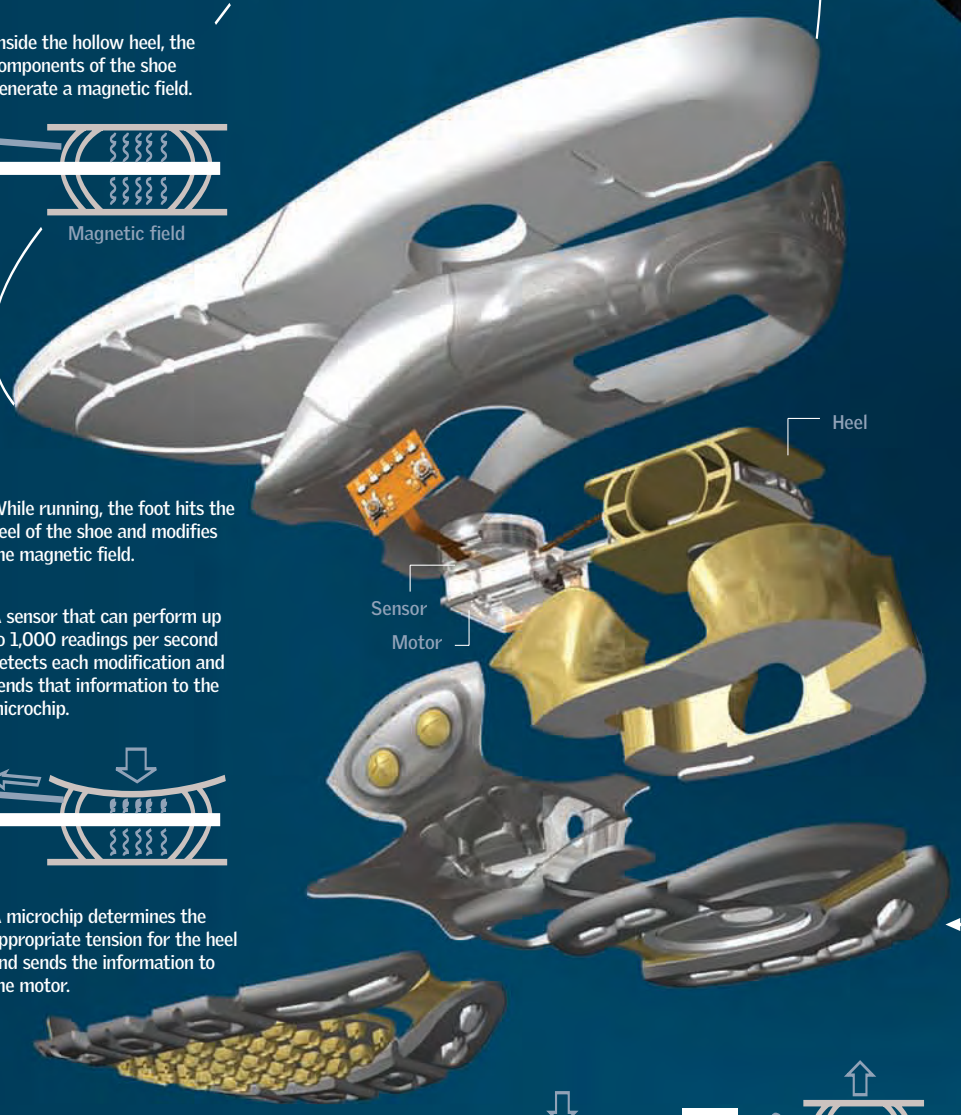
Chlorine

is an element found in the fibers of fabrics that repel germs. One of its properties is that it destroys bacterial cell walls. It is also the basis of bleach, which is frequently used in disinfectants.

Perfect Steps

The Adidas-1 shoe, a project three years in the making, can determine the athlete's weight, stride, and surrounding terrain to adjust the shoe's tension accordingly.

1. Inside the hollow heel, the components of the shoe generate a magnetic field.



2. While running, the foot hits the heel of the shoe and modifies the magnetic field.

3. A sensor that can perform up to 1,000 readings per second detects each modification and sends that information to the microchip.

4. A microchip determines the appropriate tension for the heel and sends the information to the motor.

5. The motor, rotating at 6,000 rpm, moves the screw, which in turn strengthens or relaxes the heel. The entire process is repeated with each step.

5,000,000

is the number of calculations per second performed by the Adidas-1 microchip.

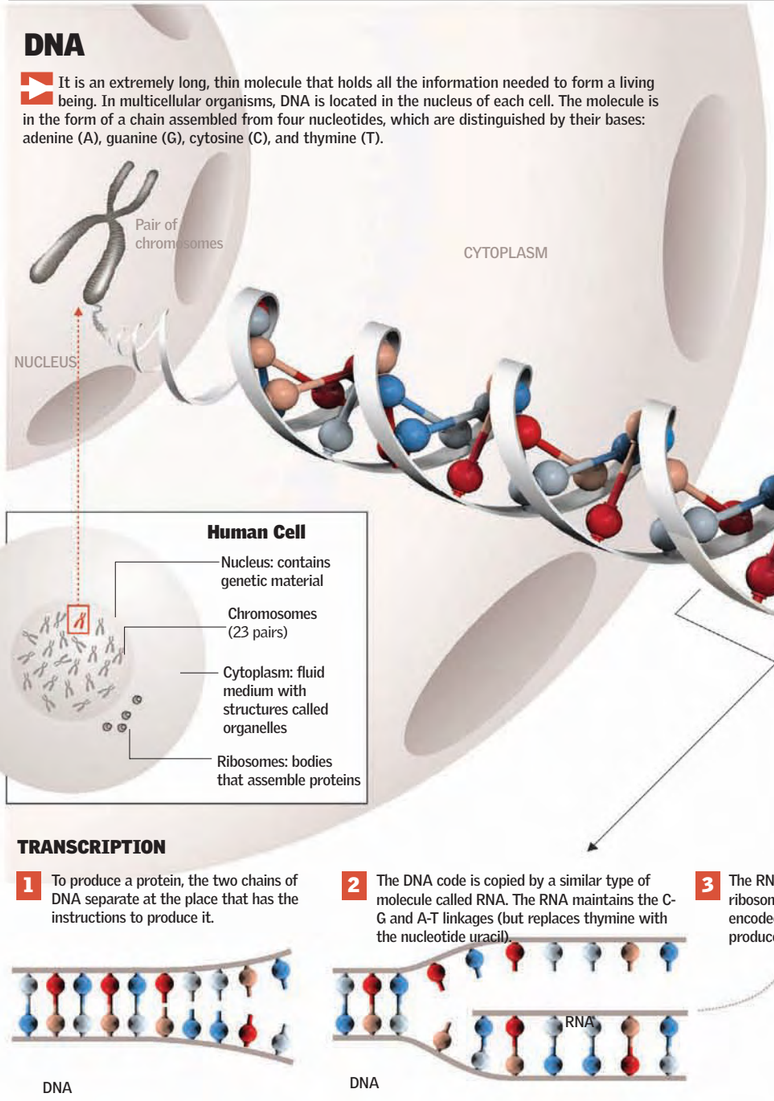
When a person is running, the body absorbs three to four times the person's weight each time a step is taken. Smart shoes help absorb this enormous force and protect the most vulnerable areas, and they also provide comfort and stability.

Biotechnology

The discovery during the 20th century that all the information that is needed to build a living being is found within each cell, written in a code with only four letters (the DNA molecule), led to the inevitable conclusion that the information could be artificially modified to produce new species with specific qualities or to cure hereditary diseases. Nevertheless, only in recent years have the techniques been developed to attain these objectives. The techniques have yielded products such as transgenic foods that have already become widely available in the marketplace and generated much controversy concerning safety and other issues.

DNA

It is an extremely long, thin molecule that holds all the information needed to form a living being. In multicellular organisms, DNA is located in the nucleus of each cell. The molecule is in the form of a chain assembled from four nucleotides, which are distinguished by their bases: adenine (A), guanine (G), cytosine (C), and thymine (T).

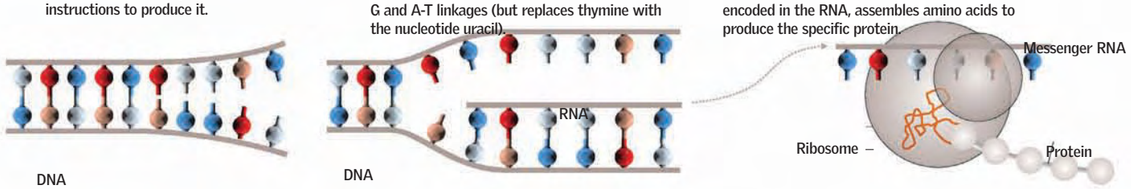


Human Cell

- Nucleus: contains genetic material
- Chromosomes (23 pairs)
- Cytoplasm: fluid medium with structures called organelles
- Ribosomes: bodies that assemble proteins

TRANSCRIPTION

1. To produce a protein, the two chains of DNA separate at the place that has the instructions to produce it.
2. The DNA code is copied by a similar type of molecule called RNA. The RNA maintains the C-G and A-T linkages (but replaces thymine with the nucleotide uracil).
3. The RNA leaves the nucleus and attaches to a ribosome, which, in accordance with the instructions encoded in the RNA, assembles amino acids to produce the specific protein.



Transgenic Organisms

A transgenic organism is an organism whose genome (the set of instructions coded by its DNA) contains a gene of another species. The gene is introduced through genetic manipulation.

Plants

There are many types of transgenic plants, in particular several crops useful in agriculture. They include soy that is resistant to herbicides, corn that produces its own insecticide, and sunflowers that are tolerant to drought.

Animals

Some transgenic animals have been created to produce medical drugs on a large scale, and some have been created for laboratory experimentation. At present, there are plans to develop transgenic pigs that could produce organs for use in human transplants.

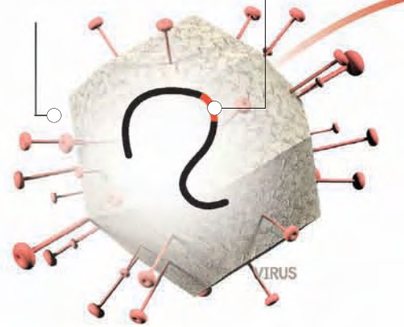
Cut and Paste

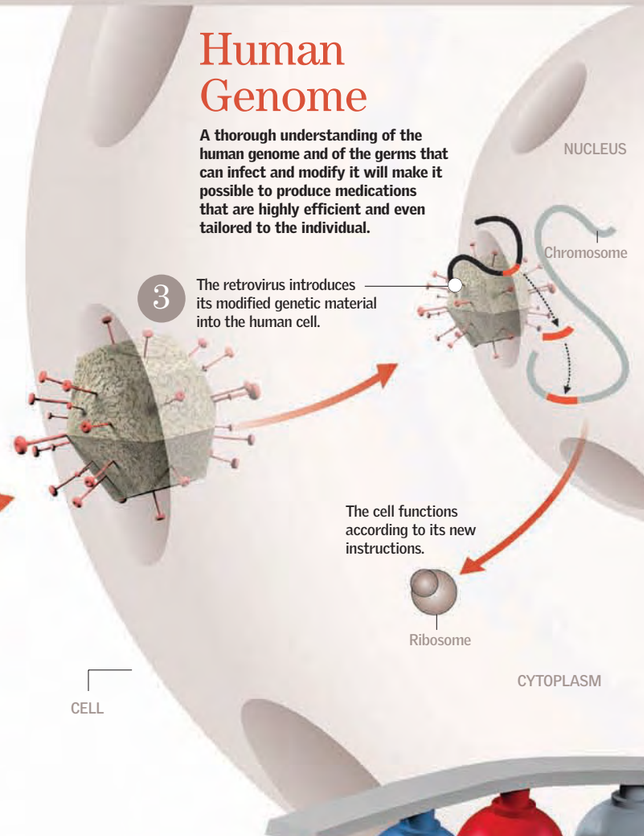
It is possible to "cut and paste" genes to correct genetic defects or, in the case of transgenic organisms, produce new species with selected properties.

Gene Therapies

Only the first steps have been taken in this specialized field, whose principle is to treat hereditary disorders by modifying a patient's DNA. Other illnesses, such as cancer and AIDS, might also be treatable with this type of therapy.

1. Gene therapy typically makes use of retroviruses to modify a person's DNA. Retroviruses can infect a human cell and use their RNA to modify the cell's DNA to convert the cells into a "virus factory." This capability is used to modify a cell's DNA in a desired way.
2. The retrovirus RNA is modified to reduce or eliminate its ability to cause disease. At the same time, an RNA fragment is added that is intended for insertion into the human cell.
3. The retrovirus introduces its modified genetic material into the human cell.



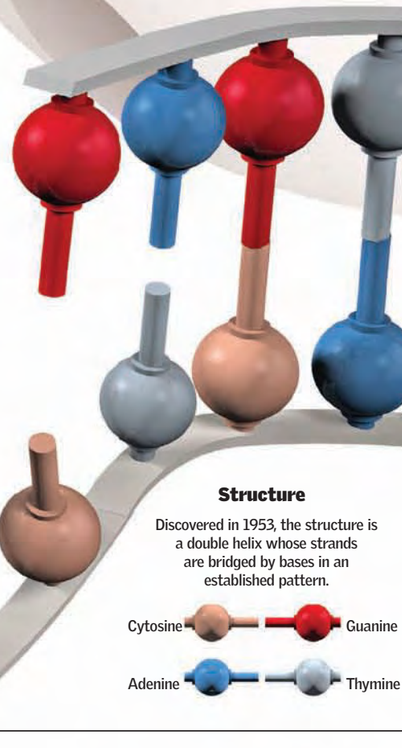


Human Genome

A thorough understanding of the human genome and of the germs that can infect and modify it will make it possible to produce medications that are highly efficient and even tailored to the individual.

3 billion

The approximate number of DNA base pairs that make up the human genome



Structure

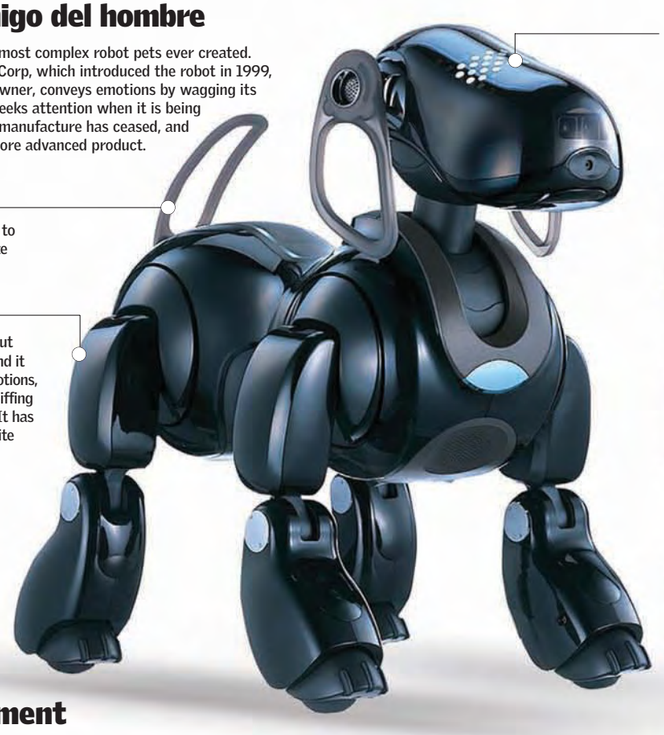
Discovered in 1953, the structure is a double helix whose strands are bridged by bases in an established pattern.

Artificial Intelligence

Although the concept of artificial intelligence (AI) had long been present in science fiction, its theoretical basis was not established until the early 1950s. At first, investigators in the discipline tackled the problem with great optimism, but over the years the challenge of creating a machine that could "feel" and behave like a human being with a capacity for abstraction—and on occasion act in an illogical manner—revealed its considerable complexity. Today there are amazing robots that still lack these human qualities.

El mejor amigo del hombre

AIBO is one of the most complex robot pets ever created. According to Sony Corp, which introduced the robot in 1999, AIBO interacts with its owner, conveys emotions by wagging its tail when it is happy, or seeks attention when it is being ignored. For the present, manufacture has ceased, and customers anticipate a more advanced product.



Touch
The robot dog is sensitive to touch; it can also recognize its owner.

Multitalented
It can move around without bumping into obstacles, and it can imitate typical dog motions, such as lying down and sniffing the ground with its nose. It has its favorite toys and favorite spots around the house.

LEDS
AIBO conveys emotions through its body movements. It also uses LED patterns to communicate with its owner.

Emotions

Happy | Angry | Sad

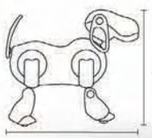
Expressions

Recognized its owner | Detected an obstacle | Has been petted

Favorites

Petted by its owner | Favorite spot | Favorite things

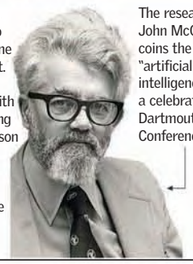
Dimensions



AI Development

The search for artificial intelligence began in the 1950s. Since then, a number of milestones have been reached. Following are some major milestones.

1950
The Turing test is published. The purpose of the test is to determine whether a machine can be considered intelligent. The challenge consists of having a person converse with a machine and a human being at the same time. If the person cannot decide which interlocutor is the human being, the machine has passed the test. For the time being, no machine has succeeded in doing so.



1956
The researcher John McCarthy coins the term "artificial intelligence" at a celebrated Dartmouth Conference.

1962
Unimation, the first company dedicated to producing robots, is formed. Four years later a computer program called ELIZA becomes available. The program uses a dialogue system that simulates a psychotherapist's speech. According to many users/patients, this system can elicit strong emotions from them.

1973
Freddy, a robot capable of identifying and assembling objects, comes into being at the University of Edinburgh, Scotland.

1994
The twin cars VaMP and VITA-2, developed by the University of Munich and Mercedes Benz, drive under automatic control, carrying live passengers about 620 miles (1,000 km) around Paris, in traffic, at speeds up to 80 miles per hour (130 km/h).

1996
The chess program Deep Blue wins a game of chess against world chess champion Garry Kasparov.

200 million

The possible number of positions evaluated each second by the improved version of Deep Blue that defeated world-chess champion Garry Kasparov

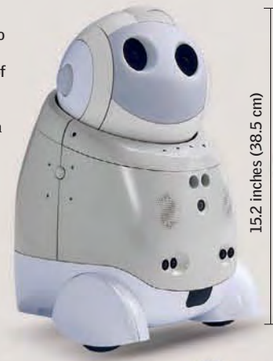
The Day a Machine Beat the Best Human

February 10, 1996, is a red-letter day in the history of artificial intelligence. On that day, an IBM computer called Deep Blue won a game of chess in a match against the world chess champion, Garry Kasparov, becoming thereby the first computer to triumph over a reigning world champion. The game was part of a match in which the Russian player prevailed four to two. In 1997, a rematch was held between Kasparov and Deep Blue, which won by a score of 3.5 to 2.5.

Humanoids

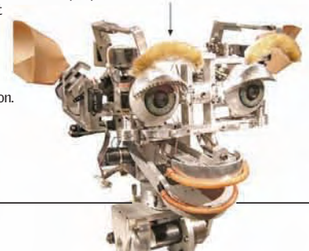
Their humanlike appearance could spark our imagination and reinforce the impression that the humanoid is a living machine. At present, commercially sold humanoids serve only as a source of entertainment.

PAPERO
Produced by NEC, PaPeRo is a domestic robot that can recognize the faces of its family members, distinguish colors, read text, dance, and change a TV channel when its owner gives a verbal command. It can tell stories to children, and, by means of its camera eyes, it can send parents images of their children while the parents are at the office.

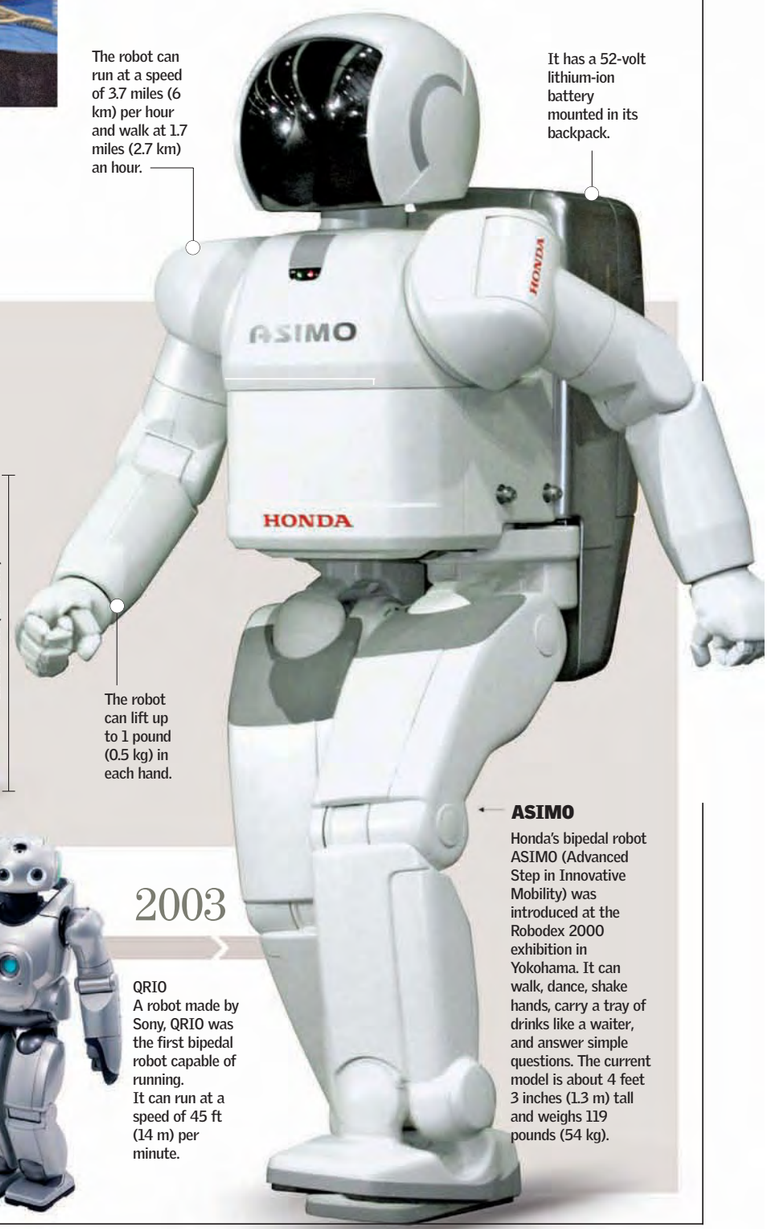


1998
Furby, a small pet that resembles a gremlin, is introduced. It can learn to talk as it grows up. It becomes a retail sensation.

1999
Cynthia Breazeal designs Kismet, one of the first robots to respond to people in a natural manner.



2003
QRIO
A robot made by Sony, QRIO was the first bipedal robot capable of running.
It can run at a speed of 45 ft (14 m) per minute.



The robot can run at a speed of 3.7 miles (6 km) per hour and walk at 1.7 miles (2.7 km) an hour.

It has a 52-volt lithium-ion battery mounted in its backpack.

The robot can lift up to 1 pound (0.5 kg) in each hand.

ASIMO
Honda's bipedal robot ASIMO (Advanced Step in Innovative Mobility) was introduced at the Robodex 2000 exhibition in Yokohama. It can walk, dance, shake hands, carry a tray of drinks like a waiter, and answer simple questions. The current model is about 4 feet 3 inches (1.3 m) tall and weighs 119 pounds (54 kg).

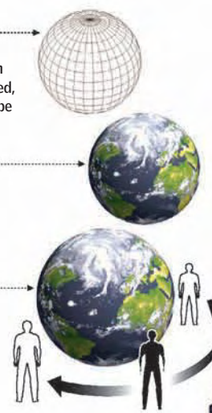
Virtual Reality

Is a technology in full development whose object is to deceive the senses to create a variety of sensations. It has many applications, which have not yet been completely explored. The focus has been on forms of entertainment in which the player acts within the created setting and on simulators for training soldiers, pilots, surgeons, and others in extreme situations without placing the trainees at risk. Other promising areas for virtual reality—which combines the capabilities of the most powerful computers with ingenious mechanical devices—are in medicine (especially in the areas of treating phobias and traumas), marketing, and publicity.

Images

are created by powerful processors that use various 3-D programming languages. VRML is one of the most widely used, although it is giving way to X3-D, which is more complex.

HOW THEY ARE GENERATED



1 Modeling
The form of the object is generated and given a skeleton framework that, when animated, can be used to modify the shape and position of the object.

2 Composition
Textures, colors, and lighting are applied, all of which help provide sensations of greater realism.

3 Programming
The user of the simulation needs to be able to interact with the object by means of the specific characteristics assigned to it.

Requirement

For many years, airline pilots have been required to practice periodically in flight simulators, one of the most widespread applications of virtual reality.

Deceiving the Senses

SIGHT
There are several means by which high-quality virtual reality misleads the sense of sight. These means include the use of special helmets and glasses and of screens that extend beyond the visual field, such as those employed in IMAX theaters.

SOUND
The challenge is to produce three-dimensional sound that simulates environmental sound. It is necessary to calculate the position of an individual with respect to the virtual sound source and objects. Good-quality simulations exist, but work remains to be done.

SMELL
Virtual-reality simulations have been developed that use strong basic odors, but they are expensive. Producing the sensation of softer and more complex aromas remains a long-term goal.

TOUCH
Some systems use gloves that can give the wearer the perception that virtual objects are present to the touch. However, a good simulation should at the same time include sensations of temperature, shape, firmness, and force—something that remains a distant goal.

TASTE
There have not been advances with this sense. It is believed that to generate taste sensations, it will be necessary to stimulate the brain directly with invasive methods akin to the neuronal sockets envisioned in the movie *Matrix*.

HELMET
generates 3-D images using complex calculations while it changes perspectives according to the head movements of the person experiencing the simulation.

DATA GLOVE
Uses electromagnetic and inertial sensors to register hand and arm movements, which are converted into electrical signals and incorporated into the simulation.

Passage to a Parallel World

Although the perfect virtual-reality setting remains to be created, there are those who already experience new sensations by simply putting on a helmet, a pair of gloves, and special boots.

EARPHONES
are designed to simulate 3-D sound by such techniques as delaying sound output from different channels by a fraction of a second to create the perception that sound sources are situated at distinct locations.

Textures

Researchers recognize that textures are some of the most difficult sensations to simulate. An experimental system that simulates the texture of various grades of sandpaper has been developed in the United States.

Controllers
The most advanced are wireless and detached—that is, unlike a conventional joystick, the controls are not mounted in any kind of structure. They transmit signals to the unit's processor with infrared radiation, and they can register placement, movement, speed, and acceleration through an inertial system.

$739,000,000

was the amount collected worldwide for the movie *Matrix Reloaded* (the final movie of the *Matrix* trilogy), making it one of the top 25 box-office hits of all time.

BOOTS
function like data gloves by providing information for the simulation. The boots indicate whether the user is running, walking, or resting.

Evolution

In almost half a century of evolution, virtual reality has progressed from an ingenious cinematic machine to a very promising complex technology.

1968
Morton Heilig, a cinematographer, constructs the Sensorama. The viewer sits in a chair that can vibrate. The viewer is surrounded by three screens on which a film, such as a bicycle trip through New York City, is projected. It produces smells, currents of air, and other effects. It was the first virtual-reality simulator.

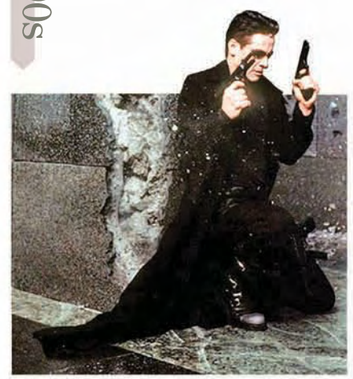
1968
Ivan Sutherland, a pioneering computer scientist, proposes the use of a video display that can be placed on a viewer's head and respond to the head's orientation to make simulations more real. The result is the head-mounted display (HMD), whose early models use mirrors in a dual-projection system.

The 1980s
1977: The first data glove is patented.

Major development takes place in fighter-aircraft simulators to train pilots using HMD.

1989: The U.S. Department of Defense creates SimNet, a simulation system to train troops.

The 1990s
Many experimental approaches to touch and smell simulators are developed while simulations for vision and sound are perfected.



Perfect Simulation

The *Matrix* trilogy, whose first movie premiered in 1999, presents an idealized virtual reality. It takes place in a world dominated by machines in which human beings live in a fictitious universe. Their brains are connected to a virtual-reality machine that creates such perfect simulations that they cannot even suspect that they inhabit an illusory world.

Soldiers of the Future

For centuries, nations have devised highly diverse means of arming and defending their soldiers. With current developments, the tendency has almost been to think of a soldier as a robotic unit, one that is in constant communication with its fellow soldiers and equipped for combat in any type of terrain, environment, or condition, using weapons that are ever more precise and lethal. Despite these advances, however, the main challenge continues to be that of dealing with the vulnerability of the soldier. Within the most modern uniforms and advanced fighting systems, there is still a human being. In this regard, developments in nanotechnology that could lead to the creation of intelligent uniforms would be truly revolutionary. ●

Land Warrior

is a term used to refer to the most modern and technological approach to equipping a ground soldier. It saw limited use in the Iraq War, but the weight of the equipment and its relatively short battery life led to the suspension of the program. Newer technologies were under study to improve it.

Infrared sensors can detect persons in absolute darkness by the heat they emit.

Camera sight The image it produces can be viewed directly in the helmet.

Multiple antennas receive and emit signals for radio, GPS, video, and other types of information. The soldier remains in constant contact with other soldiers in the unit, which helps prevent feelings of isolation.

Monocular screen can show the soldier position maps and the placement of troops, among other things. It can also show images from unmanned vehicles.

Control unit The soldier uses it to control all the systems.

Modular ceramic vest Divided into plates, it protects the soldier from projectiles the size of an M16 round.

Energy for the system The system is equipped with lithium batteries and can operate for 24 hours.

Waterproof material maintains normal body temperature, even in extreme conditions.

Mask protects against biological and chemical weapons.

Purification system for food and water provides a constant supply of potable water and of canned or dried rations, with a menu of 24 items.

Boots Lighter and reduce rubbing

$2 billion

The cost of developing the Land Warrior project over 10 years. Arming each soldier costs less than $30,000.

Unmanned Vehicles

have been designed to provide support, firepower, and reconnaissance without the presence of a human.

COUGAR
Unmanned ground attack vehicle. It provides a high level of firepower without risking the lives of human occupants.

MULE
A terrestrial vehicle designed for a variety of uses that include transportation, mine detection, and assistance providing air support.

UAV
Small reconnaissance and surveillance aircraft. Some versions can carry armament to attack specific targets.

60 hours

is the maximum autonomous flight time of a few types of UAVs (unmanned aerial vehicles). UAVs can perform very abrupt maneuvers that a human crew would not be able to tolerate.

Future Force Warrior

is a planning program for soldiers of the next decade. Various technological systems for defense, vision, and detection will be integrated in the helmet, and the development of nanotechnology could lead to "intelligent" uniforms.

HELMET
integrates infrared vision systems, heat sensors, sensors for chemical and biological weapons, and night-vision cameras. It has a head-up display that the soldier can use to monitor the surrounding area.

Weaponry
Precision bullets that are aimed at a target by detecting body heat

Uniform
Lightweight and waterproof, the uniform maintains body temperature and can change color depending on the terrain.

Sensors for detecting toxins. A microchip uses the information to release specific antidotes to protect the soldier.

Biological detectors to monitor such readings as the soldier's blood pressure and pulse

Automatic treatment of wounds by means of intelligent cloth

Masking of body temperature to evade enemy infrared sensors

Gecko technology to help the soldier climb walls

Boot
could be used to store energy from movements by means of kinetic cells.

Intimidation

In addition to having lethal systems and weapons, technological soldiers can with their appearance alone produce a psychological impact on the enemy.

In the Long Term

Although most of these systems are currently under development, it is unlikely that they will constitute part of regular-issue military equipment before the first 25 years of the 21st century.

- **Edible vaccines**
- **Food with biomarkers that help in identifying troops remotely**
- **High-nutrition food bars**
- **Uniforms with protein coating** provide shielding from enemy sensors.
- **Biometric sensors** constantly monitor physiological indicators.
- **Clothing to stop bleeding** applies precise pressure on a wounded part of the body.
- **Improved metabolism** can improve the oxygen supply to specific tissues and provide supplementary energy to specific cells.
- **Thermophysiology** Technology for precisely controlling body temperature

Space Exploration

By the end of the 20th century, all the planets of the solar system had been visited by space probes, including Uranus and Neptune, the most distant planets. In some cases, the visit was only a flyby mission, which nevertheless provided data impossible to obtain from the Earth. Other missions have involved placing space probes in orbit around a planet. Yet other missions have landed probes on Venus, Mars, and Titan (one of Saturn's moons). In 1969, humans succeeded in walking on the Moon, and there are now plans to send humans to the planet Mars.

Unmanned Spacecraft

All planetary missions have been accomplished with unmanned spacecraft. When possible their voyages have taken advantage of the gravitational field of one or more planets in order to minimize fuel requirements.

Space Shuttle

The manned spacecraft that has been used the most since its first launching in 1981. The shuttle, however, cannot go beyond a 430-mile (700-km) Earth orbit.

Space Shuttle

International Space Station

Earth

Many artificial satellites and manned missions have orbited and continue to orbit the Earth. The orbiting International Space Station always has a crew onboard.

Moon

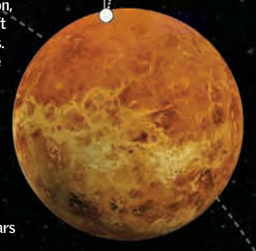
The Apollo missions (1969-72) took a total of 12 astronauts to the surface of the Moon. They are the only missions that have taken humans beyond the Earth's orbit. The United States and China are preparing new manned missions to the Moon.

Mercury

Visited in 1974-75 by Mariner 10 on three flybys, with a closest approach of 203 miles (327 km). The probe mapped 45 percent of the planet and made various types of measurements. In 2011, the probe Messenger will enter orbit around Mercury after making flybys in 2008 and 2009.

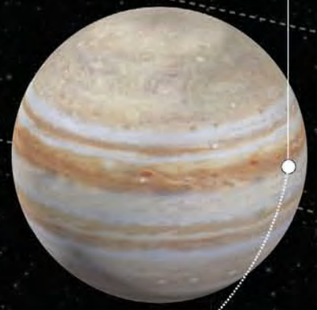
Venus

The most visited celestial body after the Moon, Venus has been studied by orbiting spacecraft and by landers, many in the 1970s and 1980s. During the Vega and Venera missions and the Mariner and Magellan missions, the surface of the planet was mapped and even excavated, and the atmosphere was analyzed. At present, the spacecraft Venus Express is studying the planet from orbit.



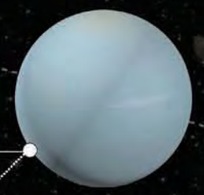
Jupiter

The giant of the solar system was visited for the first time by Pioneer 10 in 1973. Another seven spacecraft (Pioneer 11, Voyagers 1 and 2, Ulysses, Cassini, Galileo, and New Horizons) have made flybys of the planet since then. Galileo studied Jupiter and its moons for eight years from 1995 to 2003, and it transmitted images and data of incalculable scientific value.



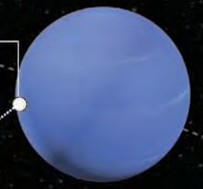
Uranus

In 1986, Uranus was visited by Voyager 2, which took photographs and readings of the planet. It is the only mission that has reached Uranus.



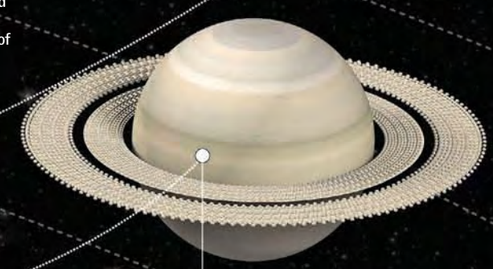
Neptune

The distant blue giant has been visited only once, in 1989, by Voyager 2.



7 years

The time it took for the Cassini probe to travel from the Earth as far as Jupiter. Galileo reached Jupiter in six years.



Saturn

Only four missions have visited Saturn. The first three—Pioneer 11 (1979), Voyager 1 (1980), and Voyager 2 (1981)—flew by at distances of 21,000 to 220,000 miles (34,000 to 350,000 km) from the planet. Cassini, in contrast, was placed in orbit around Saturn in 2004, and it has obtained amazing images of the planet and its rings. Part of the Cassini mission was to launch the Huygens probe, which successfully landed on the surface of Saturn's mysterious moon Titan.

Beyond the Solar System

Having left behind the orbit of Neptune, the space probes Pioneer 10 and 11 and Voyager 1 and 2 are bound for the edge of the solar system.

Pioneer 10 and 11

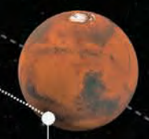
They were launched in 1972 and 1973 and visited Jupiter and Saturn. Contact with the probes was lost in 1997 and 1995, respectively. They carry a plaque with information about the Earth and human beings in anticipation that they may eventually be found by an extraterrestrial civilization. Pioneer 10 is headed toward the star Aldebaran, which it will reach in 1,700,000 years.

Voyager 1 and 2

Launched in 1977, they carry a gold-plated disk with music, greetings in various languages, sounds and photographs from the Earth, and scientific explanations. The probes passed Jupiter, Saturn, Uranus, and Neptune and remain in contact with the Earth. Some data indicate that in 2003 Voyager 1 might have crossed the heliopause, which is at the outer reaches of the solar system.

Eros

In 2000, the probe NEAR entered orbit around the asteroid 433 Eros. In 1986, six spacecraft, among them Giotto, reached Halley's Comet.



Mars

In 1965, Mariner 4 took the first 22 close-up images of Mars. Since then the planet has been visited by many orbiters and by probes that have landed on its surface. Among the most noteworthy are the missions of Viking (1976), Mars Pathfinder (1997), Mars Global Surveyor (1997), and the Mars Exploration Rovers (2004).

Mars Exploration Rover (2004)

Distance from the Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
36,000,000 miles (57,900,000 km)	67,000,000 miles (108,000,000 km)	93,000,000 miles (150,000,000 km)	141,600,000 miles (227,900,000 km)	483,000,000 miles (778,000,000 km)	887,000,000 miles (1,427,000,000 km)	1,780,000,000 miles (2,870,000,000 km)	2,800,000,000 miles (4,500,000,000 km)	

Extrasolar Planets

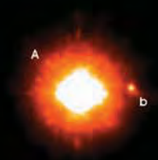
For centuries, there has been speculation about the possible existence of planets orbiting other stars in the universe in the same way that the planets of the solar system, including the Earth, revolve around the Sun. Nevertheless, it has been only a little more than a decade since it has been possible to detect such bodies—albeit indirectly—thanks to new telescopes and measuring devices with increased sensitivity. The confirmation of the existence of these extrasolar planets suddenly increases the possibility that life might exist in other corners of the cosmos.

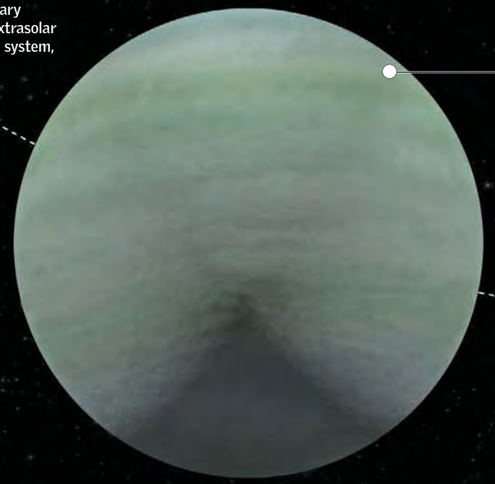
Distant Worlds

By late 2007, astronomers had detected more than 225 possible planets in about 200 extrasolar planetary systems. These figures indicate that many of these extrasolar planets form part of a system in which, like the solar system, more than one planet is in orbit around a star.

The First Photograph?

In 2004, photographs were taken that might be the first images of stars with extrasolar planets, namely 2M1207b and GQ Lup b (shown in photo). However, it is still under discussion whether these small bodies are true planets or brown dwarfs.





GASEOUS PLANETS

Almost all the extrasolar planets detected to date are gaseous giants like those of the solar system—Jupiter, Saturn, Uranus, and Neptune.

STAR

Planetary systems have been found around almost every type of star, including binary and tertiary stars and stars of various sizes and temperatures, a fact that considerably increases the possibility that some planetary systems might be inhabited.

ROCKY PLANETS

With just a few exceptions, the instruments currently used are not able to detect rocky planets like the Earth or Mars. These are the types of planets sought by astronomers, since they are the most likely to be home to life.

12.7 billion years

The age of planet PSR B1620-26b, the oldest of all the known extrasolar planets; this planet orbits a system of binary pulsars. The much-younger Earth is "only" about five billion years old.

1.2 days

The time it takes the planet OGLE-TR-56 to orbit its star; it is the shortest orbital period known for a planet.

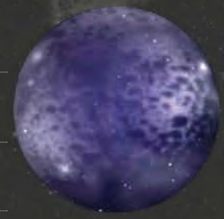
A World Similar to the Earth

Of the many extrasolar planets reported by astronomers, Gliese 581 c is the world most like the planet Earth. It orbits a red dwarf star, and it is believed that it might have the basic conditions for the development of life.

EARTH

- **Size:** 7,930 miles (12,756 km) in diameter
- **Mass:** 13.17 x 1024 pounds (5.976 x 1024 kg)
- **Distance from its star:** 93 million miles (150 million km), or 1 AU
- **Temperature:** between -112° and 122° F (-80° and 50° C)
- **Orbital period:** 365 days
- **Water:** in gaseous, liquid, and solid states

GLIESE 581 c



- **Size:** 1.5 times the diameter of the Earth
- **Mass:** 4.83 times the Earth's mass
- **Distance from its star:** One 14th the distance of the Earth from the Sun (0.07 AU)
- **Temperature:** unknown, but believed to be between 27° and 104° F (-3° and 40° C)
- **Orbital period:** 13 days
- **Water:** It would have conditions suitable for the existence of liquid water.

Notable Extrasolar Planets

Among the extrasolar planets that have been detected, there are surprising differences in their characteristics.

The First

Pegasi 51 b

Discovered in 1995, it was the first extrasolar planet found orbiting a normal star. It is a gaseous planet that has about one-half the mass of Jupiter and lies 479 light-years from the Earth.

The Hottest

HD 149026 b

This gaseous planet is similar to Saturn in terms of mass but smaller in size. It orbits its star at 25th the distance of the Earth from the Sun, and its surface temperature may be more than 2,700° F (1,500° C).

The Most Massive

Undetermined

There are several large planetary bodies that are as much as 11 times as massive as Jupiter. Planet-sized objects with a mass above this value are considered to be almost starlike bodies; they are called brown dwarfs and their classification is in question.

The Smallest

Gliese 581 c

Located about 20 light-years from the solar system, it is one of the extrasolar planets thought most likely to resemble the Earth. Its diameter is only 50 percent larger than that of the Earth.

The Closest

Epsilon Eridani b

This gaseous Jupiter-sized giant orbits the star Epsilon Eridani, which has characteristics similar to the Sun, although it is somewhat smaller and not as bright. It is only 10.5 light-years from the solar system.

The Most Distant

OGLE- 2003 -BLG-235

This planet was discovered in 2004 by means of a phenomenon called gravitational microlensing. It is a gaseous giant that revolves around a star at a distance four times greater than that between the Earth and the Sun, and it is about 19,000 light-years away.

Indirect Detection

The extrasolar planets are dark bodies very distant from the solar system, and they always lie in the glare of the star that they orbit. Therefore, they can generally only be detected by indirect methods, because "seeing" the planet is at present almost impossible.

1 The gravitational force of the planet causes a slight movement of the star toward the planet. The spectrum of the light from the star will show a redshift, which indicates that star is moving away from the Earth.

2 When the planet is situated at the opposite side of its orbit, the spectrum of the star will show a blueshift, which indicates that the star is moving toward the Earth.

This process repeats itself over and over, revealing the existence of a planet. For the movement of a planet's star to be noticeable, the planet must exert an appreciable gravitational force, which for the present means that it is only possible to detect planets that have at least four times the Earth's mass.

Tunneling Microscope

Many applications of nanotechnology continue to be explored and developed, but it was the development of the scanning tunnel microscope (STM) that made it possible to see atoms and molecules for the first time. However, this marvelous machine, whose operation is based on the quantum-mechanical concept known as the tunneling effect, is also a powerful tool. Researchers are beginning to use this new tool in the surprising new technology of manipulating individual atoms and molecules to construct novel materials and structures at a nanometer scale.

The Art of Seeing the Small

With the invention of the optical microscope by the early 17th century, it was possible for the first time to overcome the limitations of vision to peer into the world at ever-smaller scales. This invention was followed by the electron microscope, invented around the middle of the 20th century. With the introduction of the scanning tunneling microscope in the 1980s, it was finally possible to image individual atoms.

HUMAN EYE

Resolution: one tenth of a millimeter

OPTICAL MICROSCOPE

Uses visible light focused by lenses. The microscope's resolution is limited by the size of the wavelengths of light.

Magnification	Resolution:	Images:
up to 2,000 times	200 nanometers	transparent, two dimensional

TRANSMISSION ELECTRON MICROSCOPE

It illuminates the sample with focused beams of electrons—that is, it uses shorter wavelengths than those of visible light and thereby overcomes light's limitation.

Magnification	Resolution:	Images:
up to 1,000,000 times	0.5 nanometers	transparent, two dimensional

SCANNING ELECTRON MICROSCOPE

scans the sample with a beam of electrons and reads the surface.

Magnification	Resolution:	Images:
of up to 1,000,000 times	10 nanometers	opaque, three dimensional

SCANNING TUNNELING MICROSCOPE

Based on quantum principles, it makes atomic-scale imaging possible.

Magnification	Resolution:	Images:
of up to 1,000,000,000 times	0.001 nanometer (vertical) and 0.1 nanometer (horizontal)	three-dimensional graphical images of atomic structures

THE TUNNELING CURRENT

is a current of electrons that pass between the sample and probe by means of the tunneling effect. The current is generated by applying a voltage between the sample and the probe. The intensity of the current varies according to the distance between the tip of the probe and the sample—in other words, according to the relief of the sample.

THE STM PROBE

The tip of the probe is an electrical conductor that is free of oxides and comes to as sharp a point as possible—ideally a single atom.

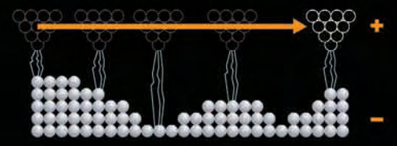
THE SAMPLE

for an STM must be either metallic or a semiconductor, and it must be very smooth. Its surface roughness should be less than one thousandth of a millimeter.

The STM in Action

To see atoms the STM reads the surface of an object with an extremely fine point, comparable to the way a person can use the tip of a finger to read Braille by detecting patterns of raised dots.

The process for reading the surface at an atomic scale requires producing a tunneling current between the STM probe and the sample. For this reason, the entire microscope functions like an electrical circuit.



The Result

is a graphic that shows the peaks and valleys of the sample's atomic and electronic structure.

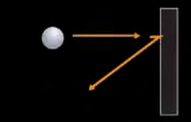
The processor converts the variations in tunneling-current intensity registered by the probe into graphics that represent the atomic structure at the surface of the sample.

The Tunneling Effect

is quantum-mechanical in nature. There is nothing analogous on the scale of humans and everyday objects.

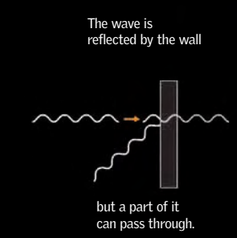
IN CLASSICAL PHYSICS

a particle cannot pass through an energy barrier (a potential barrier) if the energy of the barrier is greater than that of the particle.



IN QUANTUM MECHANICS

a particle does not have a concrete location. Instead, the particle has wavelike properties and its position is defined in terms of a probability cloud, which extends beyond the barrier. In this way, the particle can cross the barrier by, in effect, tunneling through it.



Thanks to the tunneling effect, electrons pass from the STM probe to the sample despite the barrier presented by the vacuum between them. The strength of this tunneling current is measured to determine the placement of the atoms on the sample being studied.

Nobel Prize

The physicists Gerd Binnig (German) and Heinrich Rohrer (Swiss) in 1981 established the theoretical groundwork for the development of the STM. For this work they were awarded the Nobel Prize for Physics in 1986.

Manipulation of Atoms

One of the most astonishing applications of STM is the manipulation of individual atoms and molecules as building blocks in microscopic constructions. This experimental technology might lead to the creation of new materials with unsuspected properties.

1 The probe is first used in its scanning mode to identify the atom to be moved.

2 The tip approaches the atom until it almost touches. The attractive forces generated by the tip of the probe can then pull the atom along the surface of the sample.

3 The strength of the probe's electrical field is reduced to release the atom into the desired position.

Hadron Collider

The Large Hadron Collider (LHC) is a very large scientific instrument at the European Organization for Nuclear Research (CERN). It is installed in an underground tunnel that is in the form of a ring about 5.3 miles (8.5 km) in diameter and underlies the border between France and Switzerland. The function of the instrument is to make particles collide with great energy to break them apart and obtain data concerning the basic forces of the universe. This information can lead to the discovery of new elementary particles as well as confirm the presence of elementary particles whose existence has only been determined theoretically.

The rings
The tunnels are circular, and their depth below the surface ranges from 330 to 574 feet (100 to 175 m).

The Complex

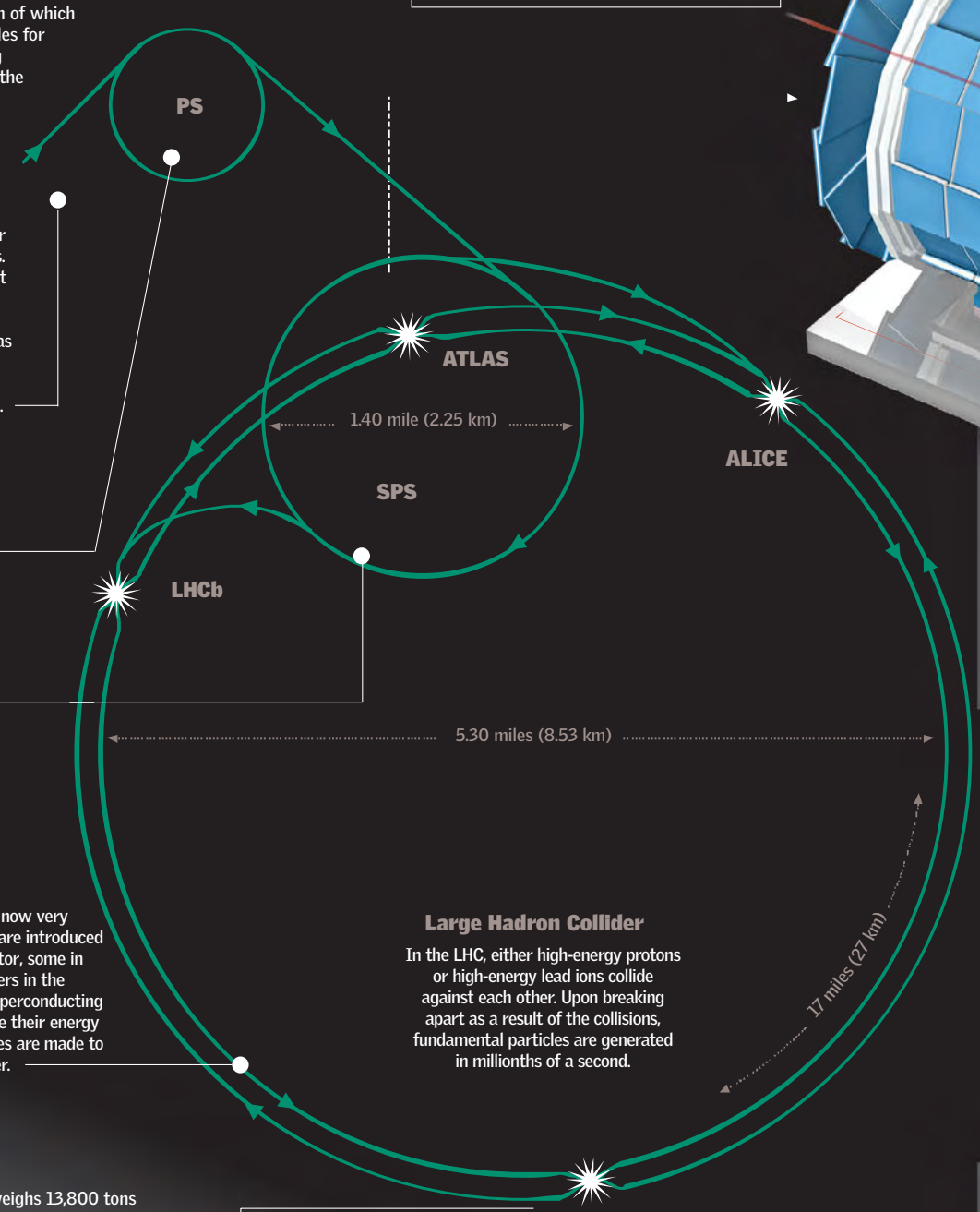
is made up of a number of tunnels in the form of rings, each of which raises the energy of the particles for the next ring. Superconducting magnets accelerate and guide the particles. Six experiments analyze the results of the collisions.

1 A linear particle accelerator separates atom nuclei from their electrons to form ions. Some ions contain just one proton (hydrogen ions), but others have more than one (such as lead ions). These ions are directed to the underground complex.

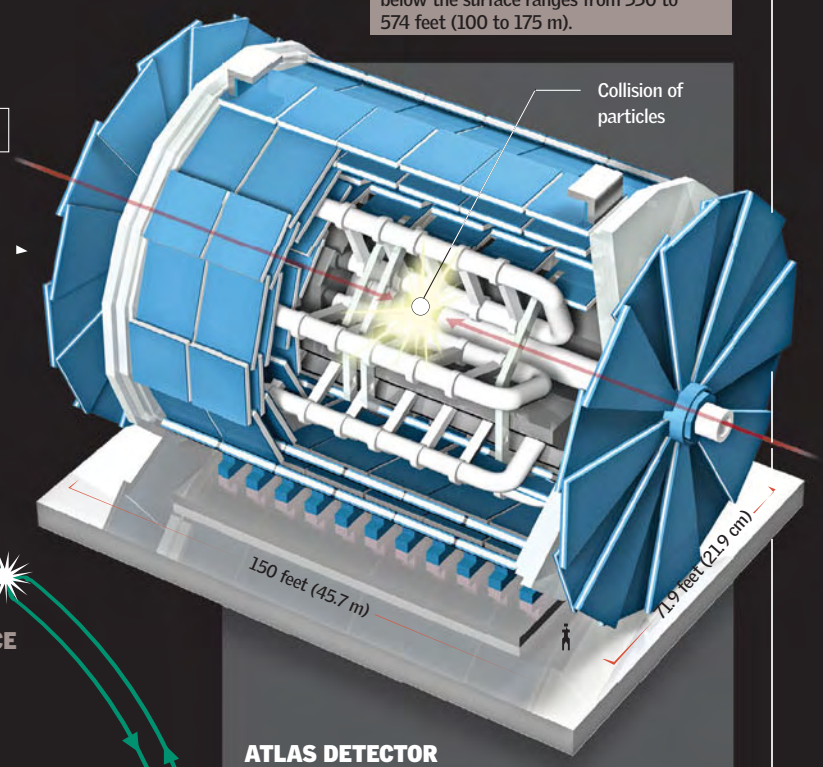
2 The ions are accelerated to reach speeds close to that of light.

3 Powerful impulses of radio waves raise the energy of the ions to 400 billion electron volts.

4 Streams of billions of now very highly energized ions are introduced into the LHC accelerator, some in one direction and others in the opposite direction. Superconducting magnets then increase their energy tenfold before particles are made to collide with each other.



Large Hadron Collider
In the LHC, either high-energy protons or high-energy lead ions collide against each other. Upon breaking apart as a result of the collisions, fundamental particles are generated in millionths of a second.



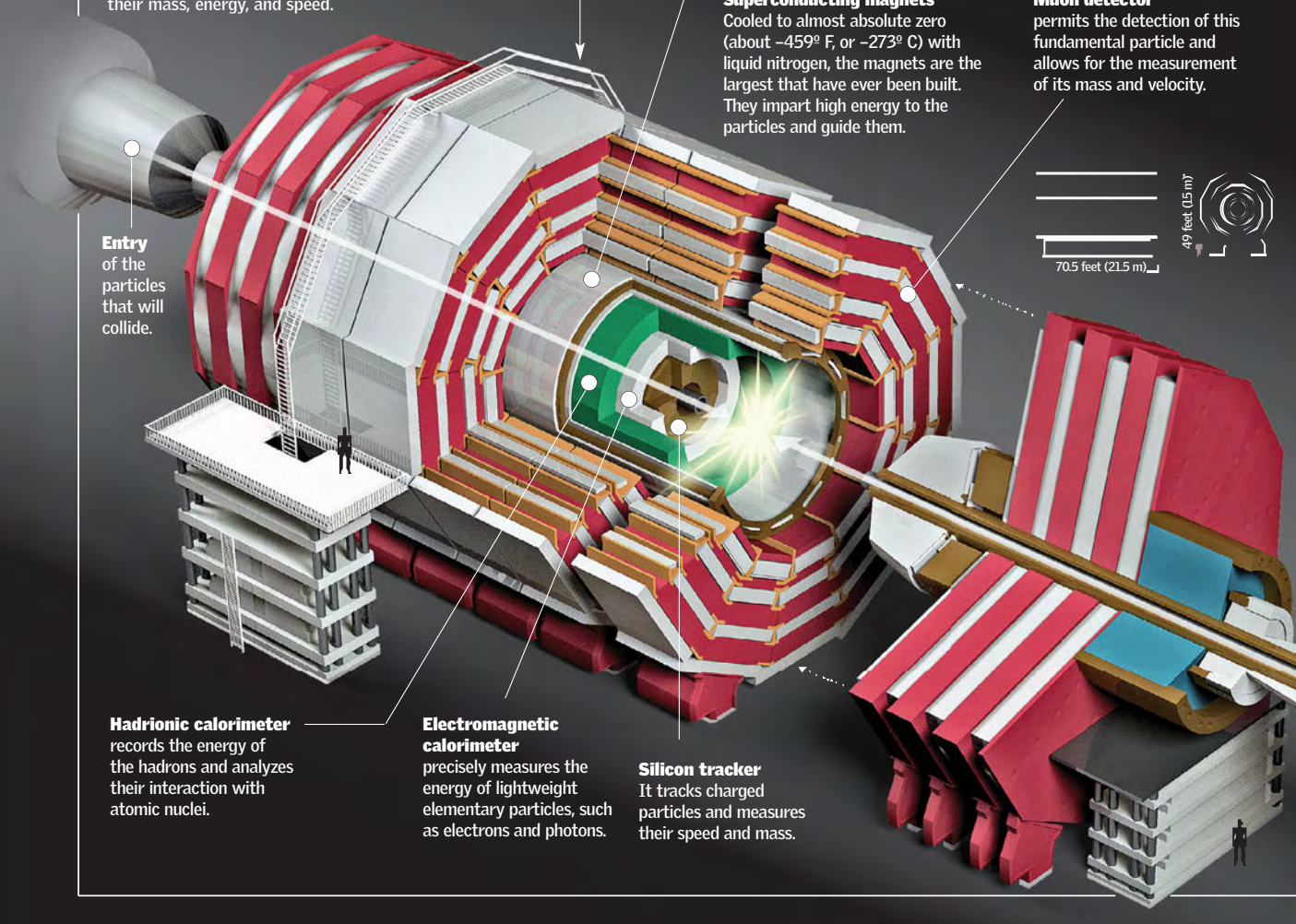
ATLAS DETECTOR
An instrument designed to explore, through particle collisions, the fundamental nature of matter and the basic forces that govern the universe. It weighs 7,700 tons (7,000,000 kg).

Big Bang

The Large Hadron Collider, by obtaining data concerning elementary particles and fundamental forces, will make it possible for us to learn the properties of the universe a fraction of a second following the big bang, the great initial explosion of the universe.

CMS Detector

This instrument, which weighs 13,800 tons (12,500,000 kg), is designed to analyze the particles (such as photons, muons, and other fundamental particles) that are generated between protons at extremely high energies and to determine their mass, energy, and speed.



Superconducting magnets
Cooled to almost absolute zero (about –459º F, or –273º C) with liquid nitrogen, the magnets are the largest that have ever been built. They impart high energy to the particles and guide them.

Muon detector
permits the detection of this fundamental particle and allows for the measurement of its mass and velocity.

Entry
of the particles that will collide.

Hadrionic calorimeter
records the energy of the hadrons and analyzes their interaction with atomic nuclei.

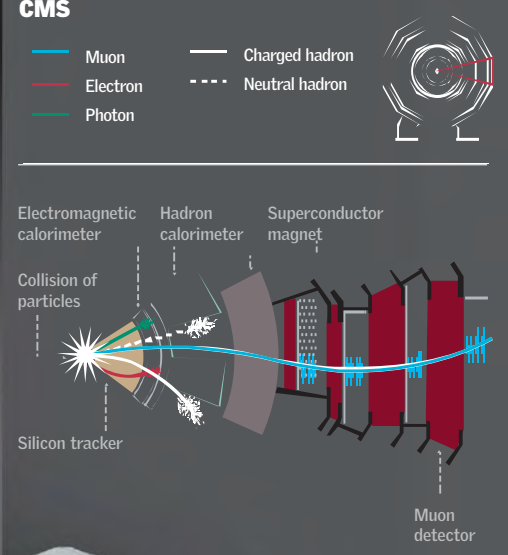
Electromagnetic calorimeter
precisely measures the energy of lightweight elementary particles, such as electrons and photons.

Silicon tracker
It tracks charged particles and measures their speed and mass.

Entry
of the particles that will collide.

A Record of the Collision

The particles that collide at high energy produce many elementary particles that exist for only millionths of a second, and they must be detected and analyzed in that short amount of time.



Glossary

Alphanumeric

Made up of letters, numbers, and other characters.

AM

In telecommunications, amplitude modulation (AM) is the linear modulation of a wave that carries information. AM works by varying the amplitude of the wave in relation to the variations of information being sent.

Amino Acid

Type of molecule that contains a carboxyl group (-COOH) and a free amino group (-NH2). It is generally represented as NH2-CHR-COOH, where R is a radical or a side chain typical of each amino acid. Many amino acids build proteins.

Amplitude

In wave mechanics, the amplitude of a wave is its maximum value, both positive and negative. The maximum positive value is known as the peak, or crest, and the negative value is the trough, or valley.

Analgesic

Any medical or paramedical procedure that relieves or eliminates pain. Although the term is sometimes used to describe any substance or mechanism that relieves pain, it usually refers to a group of drugs from a number of chemical families that relieve or eliminate pain in various ways.

Antipyretic

Drug that reduces fever. Antipyretics include acetylsalicylic acid (aspirin), dipyrone, and paracetamol. The term comes from the Greek prefix anti-, meaning "against," and pyr, meaning "fire," or "fever." Antipyretics tend to be drugs that treat fever symptomatically; that is, they do not act on the underlying cause of the fever.

Artery

In anatomy, a blood vessel that carries blood away from the heart to the rest of the body. Arteries are membranous, elastic ducts with diverging branches that distribute throughout the body the blood expelled from the ventricular cavities on each systole.

Atomic Number

The number of protons found in the nucleus of an atom. It is traditionally represented by the letter Z. The atomic number uniquely identifies a chemical element and represents a fundamental property of the atom: its nuclear charge.

Catalyst

Substance capable of accelerating or delaying a chemical reaction while remaining unaltered (it is not consumed by the reaction). This process is called catalysis. Catalysts do not alter the final energy balance of the chemical reaction; instead, they allow equilibrium to be reached at a faster or slower speed. In the natural world, there are biological catalysts, or biocatalysts, and the most important of these are the enzymes, although some ribonucleic acids also have catalytic capabilities.

Catheter

In medicine, a device that can be inserted into a body cavity or vein. Catheters allow injection of drugs, drainage of fluids, or access of surgical instruments.

Cell

Main structural and functional unit of living organisms. The term comes from the Latin word *cellula*, meaning "small compartment."

CFC

Abbreviation for chlorofluorocarbon, which is the name of each of the compounds of saturated hydrocarbons obtained from substituting hydrogen atoms for chlorine or fluorine atoms. Because of their high physical and chemical stability, CFCs have been widely used as liquid refrigerants, extinguishing agents, and aerosol propellants. Their use has been prohibited by the Montreal Protocol because they destroy the ozone layer of the stratosphere, 30 miles (50 km) above sea level.

Chromosome

Long molecular strand within the central nucleus of a cell that contains genetic material. Each chromosome is made up of a single macromolecule of DNA with associated proteins. The number of chromosomes is constant for any given species. Humans have 46 chromosomes.

Convection

Convection is one of three ways to transfer heat: it does so by transporting matter between areas with different temperatures. Convection occurs only in fluids (which include gases). When a fluid is heated, its density is reduced and it rises upon being displaced by cooler portions of the fluid. These portions in turn are heated, repeating the cycle. The result is heat transfer by means of portions of the liquid ascending and descending.

CPU

Abbreviation for central processing unit. This component executes program instructions and controls the functions of the different components of a computer. It is usually integrated into a chip called a microprocessor.

Diffraction

In physics, diffraction refers to phenomena associated with wave propagation, such as the spreading and bending of waves when they meet an obstacle. Diffraction occurs with all types of waves, whether they are sound waves, waves on the surface of a fluid, or electromagnetic waves, such as light waves and radio waves. In the electromagnetic spectrum, the lengths of X-ray waves are similar to the interatomic distances within matter. Therefore, the diffraction of X-ray waves is used as a method to explore the nature of crystalline structures. This technique allowed for the discovery of the double helix structure of DNA in 1953.

Diode

Device that allows an electric current to flow in one direction. Below a given difference of potential, a diode behaves like an open circuit (that is, it does not conduct), and above it the diode behaves like a closed circuit, with very little electrical resistance. Because of this behavior, diodes are usually called rectifiers, as they can convert alternating current to direct current.

DNA

Abbreviation for deoxyribonucleic acid. This is the primary chemical component of chromosomes and the material from which genes are made. Its function is to provide instructions needed to construct a living organism that is identical to the original (or almost identical, such as when it combines with another chain, as in the case with sexual reproduction). DNA is a polymer whose monomers are made up of a phosphate group, a deoxyribose, and a nitrogen base. These four bases are adenine (A), guanine (G), cytosine (C), and thymine (T). The DNA structure is a long chain of nucleotides in the shape of a double helix.

Electromagnetic Radiation

Combination of electric and magnetic fields, oscillating and perpendicular to each other, that propagates through an area, transporting energy from one place to another. As opposed to other types of waves, such as sound, which need a material medium to propagate, electromagnetic radiation can travel through a vacuum.

Enzyme

Biomolecule that catalyzes chemical reactions. The term comes from the Greek word *enzyme* meaning "in yeast." Enzymes are proteins. Some RNA fragments are also able to catalyze reactions related to the replication and maturation of nucleic acid.

EVA

Abbreviation for ethylene vinyl acetate. It is also known as foam rubber. EVA is a thermoplastic-type polymer that is weather resistant and chemical resistant. It has low water absorption, is environmentally friendly, and can be thrown away, recycled, or incinerated. Applications include school supplies, footwear, set design, and handicrafts. It can be washed, and it is nontoxic.

FM

In telecommunications, frequency modulation. It is the process of coding information in a carrier wave, either in digital or analog form, by instantaneous variation in its frequency according to changes in the input signal.

Frequency

In wave mechanics, the number of oscillations (or complete cycle) of a wave per unit of time (generally per second). The average human ear can perceive frequencies between 20 and 20,000 hertz (cycles per second).

Gene

Basic unit of inheritance in living organisms. Molecularly, a gene is a linear sequence of nucleotides inside a DNA molecule that contains all the necessary information to synthesize a macromolecule with a specific cellular function. Genes are found inside every chromosome and occupy a specific location known as a locus. The set of genes in a species is called its genome.

GMO

Abbreviation for genetically modified organism, an organism whose genetic material has been deliberately designed or altered. The first GMOs date back to the 1950s, when commercial strains of yeast were modified through radiation. The genetic modification of organisms is an issue of great controversy. Environmental organizations such as Greenpeace warn that the risks of GMOs have not yet been fully investigated and that GMO crops can escape control as they disperse through the action of wind and birds, thus polluting native crops. On the other hand, supporters of GMO development argue that this type of technology can alleviate world hunger and reduce the impact of certain sicknesses (for example, it is possible to grow enriched rice that can prevent infectious disease, or cows can produce vaccines or antibiotics in their milk). Because of public pressure on this issue, legislative bodies in many countries are taking it into consideration and mandating, for example, explicit labeling of foods that contain GMO soy or corn as an ingredient.

GPS

Abbreviation for Global Positioning System, a system that can determine the precise location, within inches, of a person, car, or ship anywhere in the world. GPS utilizes a network of 24 main satellites with synchronized orbits to cover the entire surface of the Earth.

Graffiti

Letters or images scrawled on private or public property, such as walls, cars, doors, and street fixtures. In everyday language, the term also includes what is known as vandalism—in other words, signs, usually with political or social messages, painted without the property owner's consent. Sometimes slogans that became popular using these techniques have also been called graffiti, such as the ones that appeared during the revolts of May 1968 in Paris: "Power to the imagination" and "Beneath the pavement is the beach."

Hardware

The physical parts of a computer. Hardware includes electronic and electromechanical devices, circuits, cables, cards, boxes, peripherals, and other physical elements related to a computer.

Hertz

The unit of frequency of the International System of Units. The hertz is named after the German physicist Heinrich Rudolf Hertz, who discovered the transmission of electromagnetic waves. One hertz (Hz) represents one cycle per second, where a cycle is the repetition of an event.

Logarithm

In mathematics, a logarithm is the inverse function of an exponential function. Thus, the logarithm to base b of a number x is the exponent to which the base has to be raised to obtain the given number. For the equation bn = x, the logarithm is a function that gives n. This function is written as n = logb x.

Macromolecule

Molecule with large molecular mass and high numbers of atoms. Macromolecules are generally the result of the repetition of one or a small number of minimal units (monomers) that make up polymers. They can be organic or inorganic, and many macromolecules are important to the field of biochemistry. Plastics are a type of synthetic organic molecules.

Microprocessor

Highly integrated set of electronic circuits used for computational calculations and controls. In a computer, this is the central processing unit (CPU).

Modulation

In telecommunications, the set of techniques that convey information in a carrier wave. These techniques allow more efficient use of communication channels, thereby facilitating the simultaneous transmission of information while protecting it from possible interference and noise.

Monomer

Small molecule that may become chemically bonded to other monomers to form a polymer. The term comes from the Greek words *mono*, meaning "one," and *meros*, meaning "part."

NTSC

The analog television encoding and broadcast system developed in the United States around 1940. It is named for the committee that developed it, the National Television Standards Committee. The NTSC standard is currently in use throughout most of North and South America and in Japan and India, among other countries.

OCR

Abbreviation for optical character recognition. It is a type of computer software designed to translate images of a text and store them in a format compatible with word-processing programs. In addition to the text itself, it can also detect the format and language.

PAL

Color-encoding system used in the broadcast of analog television systems in most of the world, PAL stands for phase alternating line. Developed in Germany, it is used in most African, Asian, and European countries, as well as in Australia and some Latin American countries.

Photoelectric Cell

Also known as photovoltaic cell, an electronic device that is sensitive to light and that can produce electricity from light. A group of photoelectric cells is called a photovoltaic panel, a device that converts solar radiation into electricity.

Polymer

Organic macromolecule composed of smaller molecules called monomers. The term is derived from the Greek words *polys*, meaning "many," and *meros*, meaning "parts."

Praxinoscope

Optical device invented in 1877 by Émile Reynaud. It used a strip of pictures placed around the inner surface of a series of spinning cylinders. A system of mirrors allowed the viewer, looking down into the cylinders, to experience the illusion of motion. In 1889, Reynaud developed the Théâtre Optique, an improved version capable of projecting images on a screen from a longer roll of pictures. This precursor to animation was soon eclipsed in popularity by the photographic film projector of the Lumière brothers.

Propellant

In aerosol spray cans, the propellant is the gas used to expel substances. CFCs were often used until it was discovered that they had negative effects on the atmosphere's ozone layer. Another propellant used in aerosol containers is butane.

Prostaglandin

Any member of a group of substances derived from fatty acids containing 20 carbon atoms. They are considered cellular mediators with a variety of effects that are frequently in opposition. The name "prostaglandin" derives from prostate gland. When prostaglandin was first isolated from seminal fluid in 1936, it was believed to be part of the prostatic secretions. In 1971, it was determined that acetylsalicylic acid could inhibit the synthesis of prostaglandins. The biochemists Sune K. Bergström, Bengt I. Samuelsson, and John R. Vane jointly received the 1982 Nobel Prize for Physiology or Medicine for their research on prostaglandins.

Recycling

Process of reusing parts or elements of an object, technology, or device that can still be used, despite belonging to something that has already reached the end of its useful life.

Semiconductor

Substance that behaves like a conductor or an insulator depending on the surrounding electric field. Silicon is used to create most semiconductors. Other semiconductor elements are germanium, selenium, tellurium, lead, antimony, sulfur, and arsenic.

SMS

Abbreviation for short message service. Usually called text messaging, SMS is a means of sending short messages to and from mobile phones, landline phones, and other handheld devices. SMS was originally designed as part of the GSM (global system for mobile communications) standard but is now available on a wide range of networks, including 3G (third-generation) networks.

Software

The set of programs and procedures that enable a computer to perform specific tasks. The term is used in contrast to the physical components of the system (hardware).

Specific Weight

Weight per unit volume of a material. In the United States, it is measured in pound-force per cubic foot (lbf/cu ft). In the metric system, it is measured in kgf/cu m, and in the International System of Units, it is measured in N/cu m.

Stroboscope

Instrument used to make a cyclically moving object appear to be stationary or slow moving. It allows turning lights on and off at a given interval any number of times. This device was used on record turntables as an indicator that the turntable was revolving at the right speed. The stroboscopic effect is what creates, for instance, the feeling of movement in a cartoon.

Telecommunications

Technique that allows the transmission of a message from one point to another, usually bidirectionally. The term is derived from the Greek word *tele*, meaning "distance." The term encapsulates all forms of long-distance communication (radio, telegraph, television, telephone, data transmission, and computer networks).

Thermodynamics

Branch of physics that studies energy—the way it is transformed into its various manifestations, such as heat, and its capacity to produce work. It is closely related to statistical mechanics, from which one can derive many thermodynamic relationships. Thermodynamics studies physical systems at the macroscopic level, whereas statistical mechanics usually describes the same phenomena at the microscopic level.

Toner

Also known as "dry ink" because of its functional similarity to ink, toner is a fine powder, usually black, that is deposited on the paper to be printed by way of electrostatic attraction. Once the pigment adheres, it binds to the paper by applying the necessary pressure or heat. Because there are no liquids involved, the process was originally called xerography, from the Greek word *xeros*, meaning "dry."

Transgenic

See GMO.

Transistor

Semiconductor electronic device used to amplify electric currents, generate electric oscillations, and perform modulation, detection, and switching functions. Its name is a combination of the words "transfer" and "resistor."

Trigonometry

Trigonometry, which in Greek means "triangle measure," is a branch of mathematics that studies angles, triangles, and the relationships between them (trigonometric functions). There is an enormous number of applications of trigonometry. For example, the technique of triangulation is used in astronomy to measure the distance to nearby stars and in geography to measure distances between landmarks; it is also used in satellite navigation systems.

Tungsten

Tungsten, also called wolfram, is a chemical element that has the atomic number 74 and belongs to group 6 of the periodic table of elements. Its symbol is W, and it is the only chemical element with two common names. Tungsten is a scarce metal that is found in certain minerals located in the Earth's crust. It is steel-gray in color, is very hard and heavy, and has the highest melting point of all the elements. It is used in light-bulb filaments, electrical resistors, and (when alloyed with steel) tool manufacturing.

Vein

In anatomy, a vein is a blood vessel that carries blood from the capillaries toward the heart. There are more veins in the human body than arteries, and the precise locations of veins vary much more from person to person.

Wavelength

In wave mechanics, wavelength is the distance, measured in the direction of the propagating wave, between repeating units of the propagating wave at a given frequency, such as peaks or adjacent valleys.

Zoetrope

Stroboscopic optical mechanism invented in 1834 by William George Horner. It consisted of a cylinder with vertical slits cut along the sides. The spectator looked through the slits at the pictures on the opposite side of the cylinder's interior. As the cylinder spun, the viewed images produced the illusion of motion. It was a very popular toy at the time and one of the precursors of cinematography. The term is derived from the Greek words *zoe* ("life") and *trope* ("turn").

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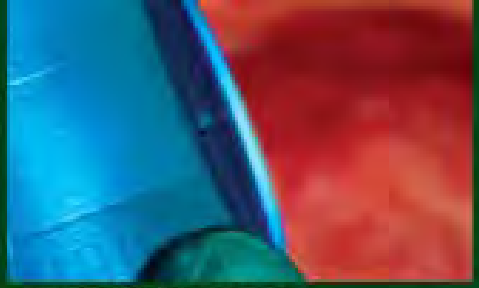

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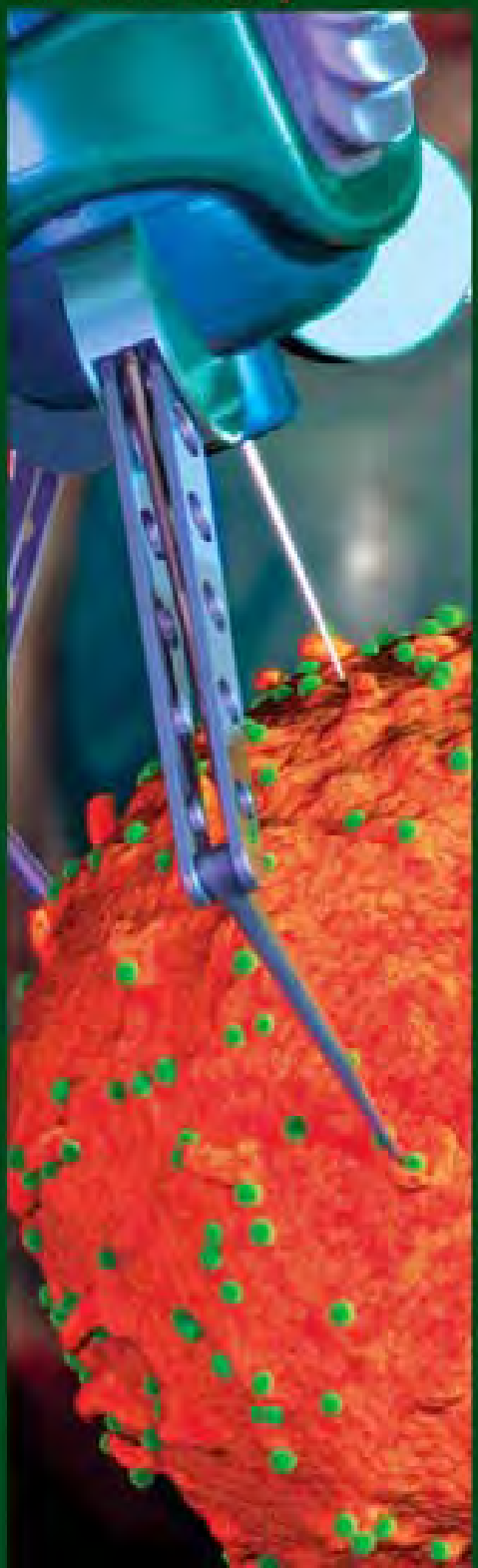

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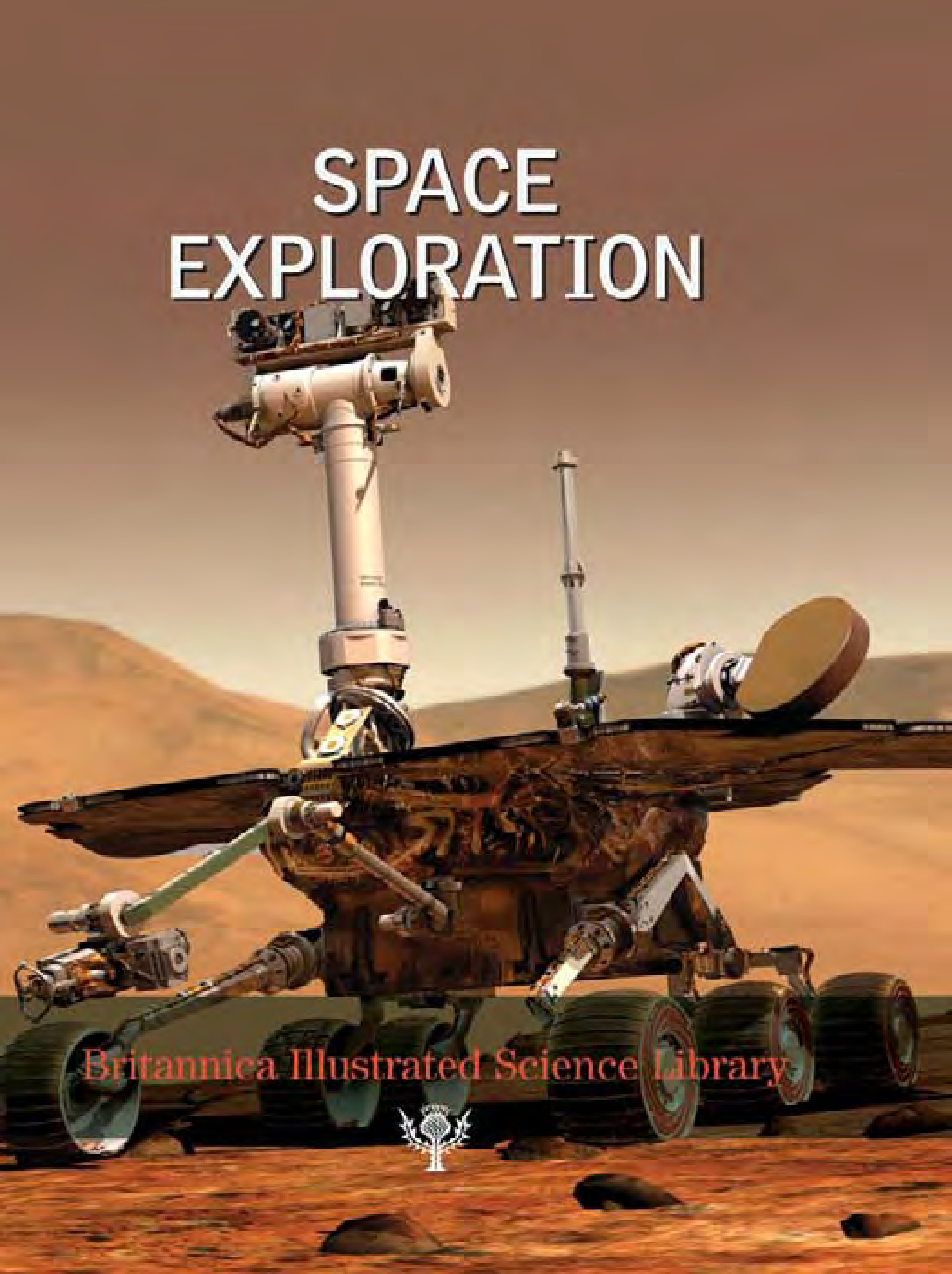

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Space Exploration

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Icecap on the south pole of Mars. The image was captured by the Mars Express space probe in December 2004.

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A Voyage into the Future

During the greater part of our history, the Moon was quite unreachable. It did not seem very big and far away but rather small. For the Greeks, the idea of walking on the Moon was certainly unthinkable, and as recently as the end of the 19th century many people doubted that humans would even be able to fly. Nevertheless, on July 20, 1969, the miracle happened. Since then many historic missions to explore the planets have been planned and executed, with the spacecraft and probes Mariner, Viking, Pioneer, Voyager, and Galileo leading the way. Thanks to human intelligence and effort we have succeeded in exploring many corners of our solar system. This book intends to show all this: the history of manned and unmanned voyages and the discoveries that were made. We will try, using simple and accessible language, to answer many questions, such as what rockets are, how they work, what shuttles exist, how astronauts live in space, and which robot probes are visiting other planets looking for signs of life. All this is accompanied by photographs and top-quality illustrations, providing a better picture of the successes by which we have made giant steps in our understanding of the composition of the other planets, their origin, and their evolution. Every day astronomers are more convinced that there are other places in the universe that are like Earth. We only have to find them. They also assure us that this is one of the most interesting moments in the exploration of the solar system, because so many things are being revealed. Orbiting spacecraft such as Mars Odyssey and Mars Express have confirmed the existence of ice under the surface of Mars. Sending exploratory spacecraft to Saturn was another prodigious feat, a demonstration of human capacity to dream of new worlds. Recently the New Horizons, whose final destination will be Pluto in 2015, lifted off. This shows that the search has only begun. There is still far to go. Perhaps life may be found farther away than we had imagined. Or maybe, as some dreamers imagine, in the next decade we will realize the project of colonizing other planets. For now, the best candidate for us to land on is Mars. But that is still only a dream, the same kind of dream that was made into reality when humans left their footprints on the Moon.

THE IMPRINT OF HUMANKIND
The footprints of the astronauts are clearly visible in the soil of the Moon.

The Conquest of Space

YURY GAGARIN
The Russian cosmonaut in the cabin of the spacecraft Vostok 1.

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The human adventure in space began with Yury Gagarin, the first Russian astronaut, who in 1961 reached an altitude of 196 miles (315 km) and orbited the Earth in the spacecraft Vostok 1. The cosmonaut had practically no control over the apparatus, which was remotely controlled by Soviet engineers. The next step was made by the United States with the arrival of astronauts on the Moon. Neil Armstrong became the first man to set foot on the Moon, followed by Edwin Aldrin. The success of the Apollo 11 mission marked the culmination of a long and costly space project whose objective was to explore Earth's only natural satellite. In the following decades, the space program has had many significant successes. ●

Destination: Other Worlds

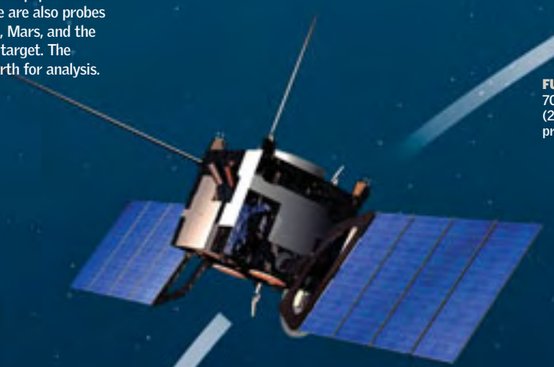
The space age began in 1957 with the launching of the first artificial satellite. Since that time, astronauts and space probes have left the Earth to investigate space. To date, 12 men have visited the Moon. Advances in astronautics have made it possible to develop automatic navigational systems with which a spacecraft can reach and enter orbit around a planet. The Mars Express probe, launched in 2003 to take photographs of Mars, used this system. Mars Express, one of the European Space Agency's most productive missions around the Red Planet, is powered exclusively by solar energy.

Automatic Navigational System

Spacecraft that are unmanned, such as the artificial satellites that orbit planets, transmit their information to Earth using radio equipment. The area of satellite coverage depends on the type of orbit. There are also probes that touch down on the surface, as was the case with Venus, Mars, and the Moon. The real work begins when the apparatus reaches its target. The instruments are activated to gather data that are sent to Earth for analysis.

CONVENTIONAL NAVIGATION

During the encounter, Earth-based optical navigation is limited by the time it takes a radio signal to reach the spacecraft.

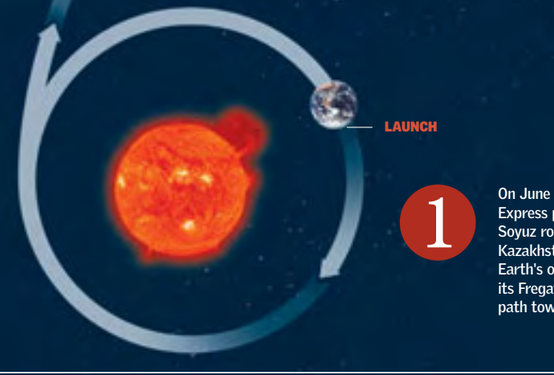


SOLAR PANEL
Provides energy for navigation

FUEL TANKS
70 gallons (270 l) of propellant each

THRUSTER
Used to correct the orbit

HIGH-GAIN ANTENNA
For long-distance communication with Earth



1 On June 2, 2003, the Mars Express probe left Earth on a Soyuz rocket launched from Kazakhstan. Once it escaped Earth's orbit, the probe activated its Fregat boosters and began its path toward the orbit of Mars.

2 The probe deploys its solar panels and begins its own life running on solar energy. It sends signals to Earth to check that its instruments are working properly.

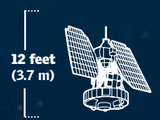
3 Mars Express begins its voyage toward Mars, which will last almost seven months. The probe is monitored from Mission Control Center in Darmstadt, Germany. Communication with the probe is done by radio. To avoid colliding with Mars, the Mars Express corrects its trajectory.

4 The transmission of data to Earth is carried out when the probe is at the maximum height of its orbit around Mars. At that moment, the high-gain antenna turns away from the Red Planet to aim toward the Earth. Mars Express began orbiting Mars in December 2004.

Space Programs

The voyages are planned years in advance. Space probes are automatic vehicles that can use the gravitational field of one planet to reach another. Some only pass at a preset distance from the planet they are studying; others (orbiters) follow a route that places them in planetary orbit. From there they can send smaller landing probes, which deploy data-collecting instruments. Manned spacecraft, however, require designs that include air, water, food, seats, and rest areas, as well as navigation-, control-, and information-transmission equipment.

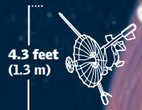
UNMANNED



ARTIFICIAL SATELLITE IN POLAR ORBIT
Nimbus

METEOROLOGICAL SATELLITE
GOES

FLYBY SPACE PROBE
Mariner



ORBITING SPACE PROBE
Galileo

PROBE WITH A LANDING DEVICE
Viking

EXPLORATION VEHICLE
Sojourner

SPACE WALK

To gather more information, the astronauts conduct a space walk outside the spacecraft.

MANNED

VOSTOK PROGRAM
Vostok 1

APOLLO PROGRAM
Apollo 11

GEMINI PROGRAM
Gemini 8

SPACE SHUTTLE
Columbia

SPACE STATION
Mir

SPACE STATION
Skylab

From Fiction to Reality

Astronautics was born toward the end of the 19th century, when the Russian Konstantin Tsiolkovsky foresaw the ability of a rocket to overcome the force of gravity. Other pioneers were Hermann Oberth, who designed a liquid-fueled missile in 1917, which was later built by the American Robert Goddard in 1926. The German Wernher von Braun built the Redstone, Jupiter, and Saturn rockets, which made the manned landing on the Moon possible. Astronautics officially began in 1957 with the launching of the first artificial satellite, Sputnik 1. The second was Sputnik 2, which had on board the dog Laika.

Sputnik 1

inaugurated the period of Russian supremacy in the so-called space race. Sputnik 1, launched in 1957, was an aluminum sphere 23 inches (58 cm) in diameter. It had instrumentation that for 21 days sent back information about cosmic radiation, meteorites, and the density and temperature of the Earth's upper atmosphere. It was destroyed by aerodynamic friction when it reentered the atmosphere 57 days later.

THE SECOND
Robert Goddard designed a rocket 10 feet (3 m) high. After ignition, it rose 40 feet (12 m) and then crashed 184 feet (56 m) away.

Robert Goddard
1882-1945
The U.S. physicist studied rockets and demonstrated their use for space travel.

THE FIRST
In Germany, Hermann Oberth designed a liquid-fueled missile in 1917 that would promote the idea of spaceflight.

Hermann Oberth
1894-1989
The scientist who worked on rocket technology during World War II.

THE THIRD
Wernher von Braun, working for NASA, was the creator of the Saturn V rocket, which carried astronauts to the Moon a number of times between 1969 and 1972.

Wernher von Braun
1912-1977
The German physicist worked for Adolf Hitler designing ballistic missiles.

SPUTNIK 1

Launch	October 1957
Orbital altitude	370 miles (600 km)
Orbital period	97 minutes
Weight	184 pounds (83.6 kg)
Country	USSR

WEIGHT ON THE EARTH
184 pounds
(83.6 kg)

ANTENNAS
Sputnik 1 had four antennas between 79 and 9.5 feet (2.4-2.9 m) long.

With a Dog

Sputnik 2 was the second satellite launched into Earth's orbit by the Russians (on Nov. 3, 1957) and the first one to carry a living creature, the dog Laika. The satellite was 13 feet (4 m) long and 6 feet (2 m) in diameter. The dog was connected to a machine that registered her vital signs, and oxygen was provided to her by an air regeneration system. Food and water were dispensed in the form of a gelatin.

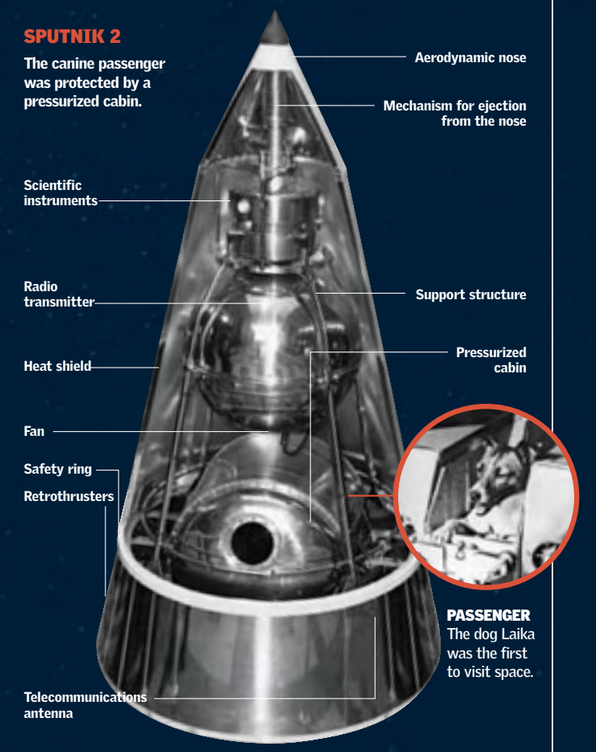
SPUTNIK 2

Launch	November 1957
Orbital altitude	1,030 miles (1,660 km)
Orbital period	103.7 minutes
Weight	1,118 pounds (508 kg)
Country	USSR

WEIGHT ON EARTH
1,118 pounds
(508 kg)

DIMENSIONS
Sputnik 2 was 13 feet (4 m) long and 6 feet (2 m) in diameter at the base.

SPUTNIK 2
The canine passenger was protected by a pressurized cabin.



PASSENGER
The dog Laika was the first to visit space.

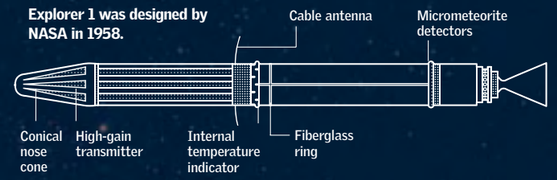
Explorer 1

The United States independently developed its first satellite, Explorer 1, which was launched from Cape Canaveral in 1958. The satellite was a cylinder 6 inches (15 cm) in diameter; it weighed 31 pounds (14 kg) and measured cosmic radiation and meteorites for 112 days, which led to the discovery of the Van Allen belts. It was designed and constructed by the Jet Propulsion Laboratory of the California Institute of Technology.

EXPLORER 1

Launch	Jan./Feb. 1958
Orbital altitude	1,580 miles (2,550 km)
Orbital period	114.8 minutes
Weight	31 pounds (14 kg)
Organization	NASA

PIECE BY PIECE
Explorer 1 was designed by NASA in 1958.



WEIGHT ON EARTH
31 pounds
(14 kg)

DIMENSIONS
Explorer 1 weighed 31 pounds (14 kg) and was 2.6 feet (0.8 m) high and 6 inches (15 cm) in diameter.

1609 GALILEO
constructed the first astronomical telescope and observed the craters on the Moon.

1798 CAVENDISH
demonstrated that the law of gravity applies to all bodies.

1806 ROCKETS
The first military rockets were invented. They were used in an aerial attack in 1814.

1838 DISTANCE
The distance to the star 61 Cygni was measured, using the Earth's orbit as a baseline.

1926 THE FIRST ROCKET
Robert Goddard launched the first liquid-fueled rocket.

1927 ASSOCIATION
On July 5 the German Association for Spaceflight was formed.

1932 VON BRAUN
began his investigations on rockets for the German military.

1936 LABORATORIES
Guggenheim Aeronautical Laboratory. Later its name was changed to the Jet Propulsion Laboratory.

1947 ROCKET PLANE
Chuck Yeager broke the sound barrier aboard the rocket plane X-1.

1949 BUMPER
The first stage of a two-stage rocket, which reached an altitude of 244 miles (393 km)

1957 SPUTNIK 1
On October 4 the Soviet Union launched the Sputnik 1 satellite into space.

NASA Yesterday and Today

The National Aeronautics and Space Administration (NASA) is the agency that organized the U.S. space program. It was created in 1958 as part of the space race with the then Soviet Union. It planned all national activities linked with space exploration. It has a launch center (the Kennedy Space Center) and other installations all over the country.

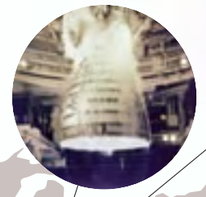
NASA Centers

NASA's activities in astronautics and space research are so numerous and so varied that it has different complexes all over the United States. The agency has a number of installations for research, flight simulation, astronaut training, and preparation. NASA's headquarters are in Washington, D.C., and the Mission Control Center is in Houston. Another important center is the Jet Propulsion Laboratory, whose responsibilities include managing the Deep Space Network, which maintains constant communication with space missions through its facilities in California, Spain, and Australia.

AMES RESEARCH CENTER
Founded in 1939, it is the experimental base for many missions. It is equipped with flight simulators and advanced technology.

LYNDON B. JOHNSON CONTROL CENTER
Astronauts are selected and trained at the Houston center. Spaceflight takeoffs and landings are controlled from here.

MARSHALL SPACE FLIGHT CENTER
manages the transport of equipment, the propulsion systems, and the launching of the space shuttle.

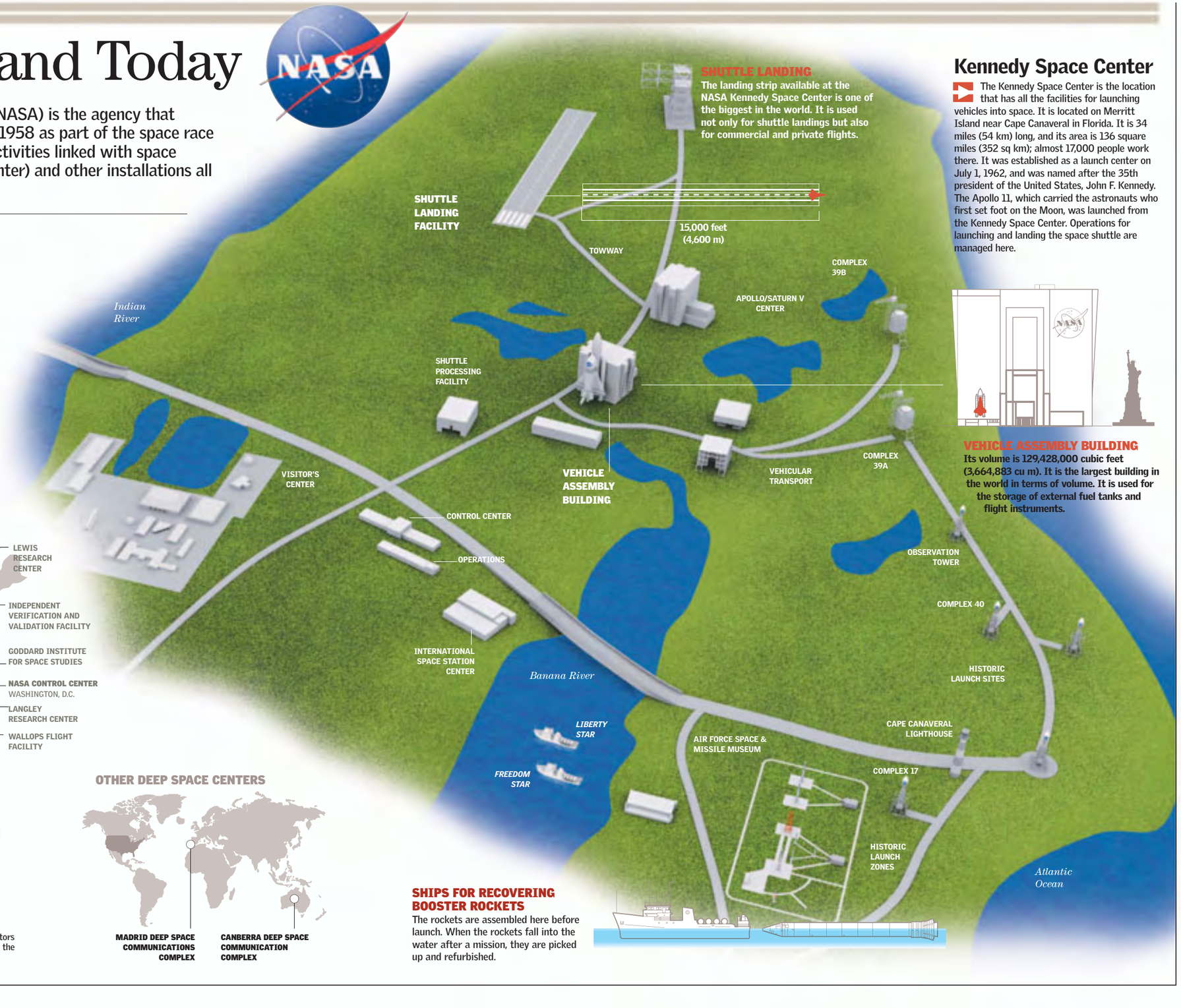


JET PROPULSION LABORATORY
designs flight systems and provides technical assessment. Directs the Deep Space Network.

DRYDEN FLIGHT RESEARCH CENTER
is involved in atmosphere-related activities. It has been in operation since 1947.

GODDARD SPACE FLIGHT CENTER
designs, manufactures, and monitors scientific satellites to investigate the Earth and other planets.

OTHER DEEP SPACE CENTERS



Kennedy Space Center

The Kennedy Space Center is the location that has all the facilities for launching vehicles into space. It is located on Merritt Island near Cape Canaveral in Florida. It is 34 miles (54 km) long, and its area is 136 square miles (352 sq km); almost 17,000 people work there. It was established as a launch center on July 1, 1962, and was named after the 35th president of the United States, John F. Kennedy. The Apollo 11, which carried the astronauts who first set foot on the Moon, was launched from the Kennedy Space Center. Operations for launching and landing the space shuttle are managed here.

VEHICLE ASSEMBLY BUILDING
Its volume is 129,428,000 cubic feet (3,664,883 cu m). It is the largest building in the world in terms of volume. It is used for the storage of external fuel tanks and flight instruments.

SHIPS FOR RECOVERING BOOSTER ROCKETS
The rockets are assembled here before launch. When the rockets fall into the water after a mission, they are picked up and refurbished.

Other Space Agencies

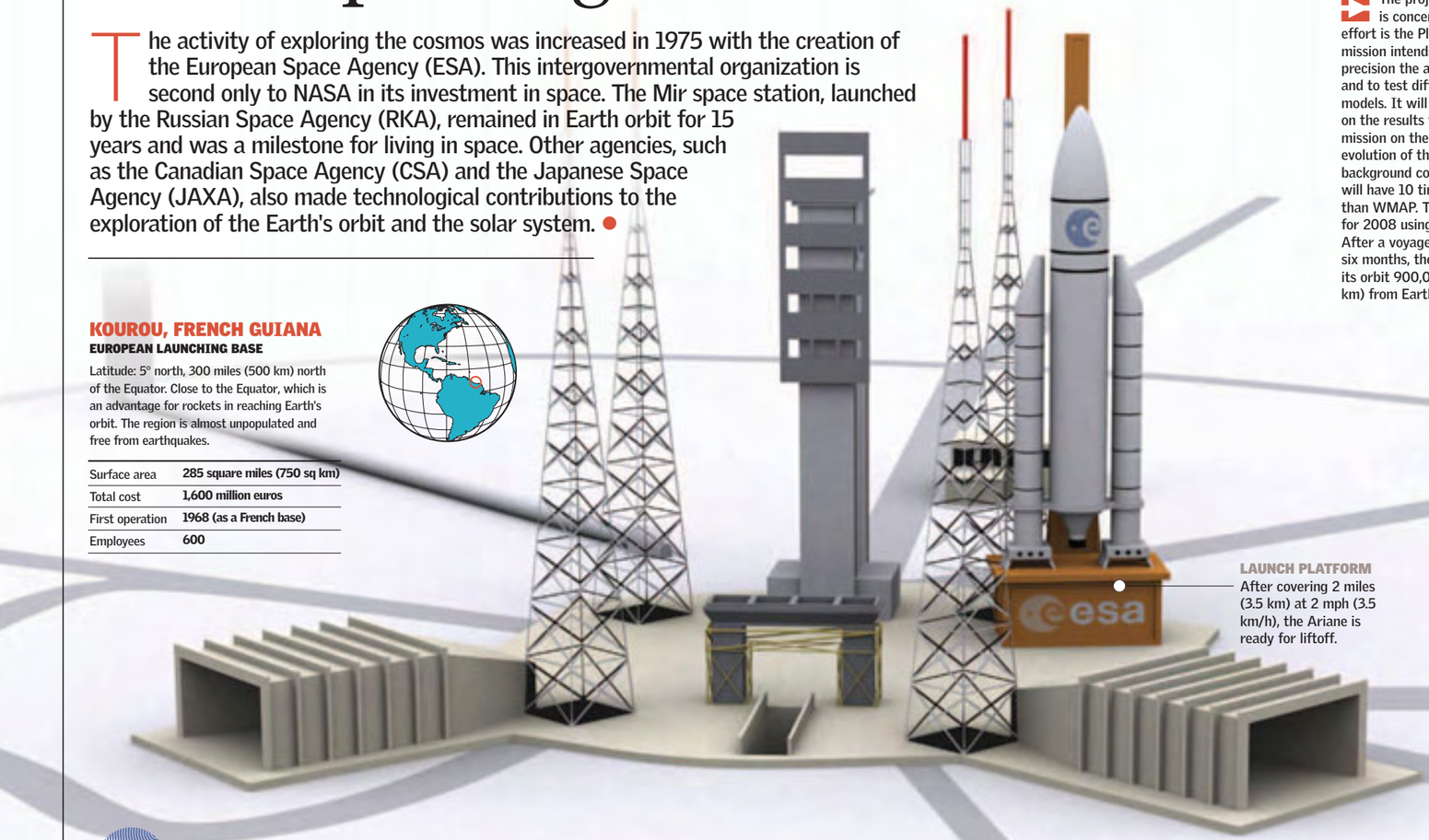
The activity of exploring the cosmos was increased in 1975 with the creation of the European Space Agency (ESA). This intergovernmental organization is second only to NASA in its investment in space. The Mir space station, launched by the Russian Space Agency (RKA), remained in Earth orbit for 15 years and was a milestone for living in space. Other agencies, such as the Canadian Space Agency (CSA) and the Japanese Space Agency (JAXA), also made technological contributions to the exploration of the Earth's orbit and the solar system.

KOUROU, FRENCH GUIANA

EUROPEAN LAUNCHING BASE

Latitude: 5° north, 300 miles (500 km) north of the Equator. Close to the Equator, which is an advantage for rockets in reaching Earth's orbit. The region is almost unpopulated and free from earthquakes.

Surface area	285 square miles (750 sq km)
Total cost	1,600 million euros
First operation	1968 (as a French base)
Employees	600



LAUNCH PLATFORM
After covering 2 miles (3.5 km) at 2 mph (3.5 km/h), the Ariane is ready for liftoff.

TRANSPORT ROUTE

TOWARD THE FINAL DESIGN
The rocket goes to the assembly building for final details.

ASSEMBLY BUILDING
Once the process is complete, the rocket is transferred to the platform.

Mission Threshold

The project on which the ESA is concentrating the most effort is the Planck mission. The mission intends to establish with precision the age of the universe and to test different expansion models. It will also seek to improve on the results from the U.S. WMAP mission on the formation and evolution of the universe and the background cosmic radiation. Planck will have 10 times better resolution than WMAP. The launch is planned for 2008 using an Ariane rocket. After a voyage of between four and six months, the satellite will adjust its orbit 900,000 miles (1.5 million km) from Earth.

PLANCK MISSION

Launch year	2007
Estimated duration	21 months
Launch vehicle	Ariane 5
Weight at launch	4,000 lb (1,800 kg)

Canadian Space Agency

The CSA was created in 1990, although it had prior involvement in astronautic activities. The first Canadian launch occurred in 1962 with the Alouette 1 satellite. The most important work of the CSA is Radarsat, launched in November 1995. It provides information about the environment and is used in cartography, hydrology, oceanography, and agriculture. The Canadian agency also participated in the International Space Station (ISS) by providing the robot arm called the Mobile Service System (MSS).

Japanese Space Agency

On Oct. 1, 2003, three independent organizations were combined to form the JAXA: the Institute of Space and Astronautical Science (ISAS), the National Aerospace Laboratory (NAL), and the National Space Development Agency (NASDA). Its most outstanding mission is the Hayabusa, launched in May 2003 as the first mission designed to land on an asteroid. It reached the asteroid Itokawa in November 2005. Despite problems with the probe, controllers expect it to return to Earth in 2010 with samples taken from the surface of the asteroid.

Russian Federal Space Agency

Formed after the dissolution of the Soviet Union, it uses the technology and launching sites that it inherited from the Soviet space program. The Russian agency was responsible for orbiting the Mir space station, the direct predecessor of the International Space Station. Mir was assembled in orbit after separate launches of different modules between 1986 and 1996. It was destroyed in a controlled manner at the end of its useful life on March 23, 2001.

MIR STATION
housed the cosmonauts and astronauts in space.

PROGRESS-M
used to supply food and fuel.

USEFUL LIFE
15 years

SOLAR PANELS
supply the station with electricity from solar energy.

PRINCIPAL MODULE
used as living quarters and general control of the station.

SOYUZ ROCKET
The rocket of the Russian agency that is used to put spacecraft into orbit.

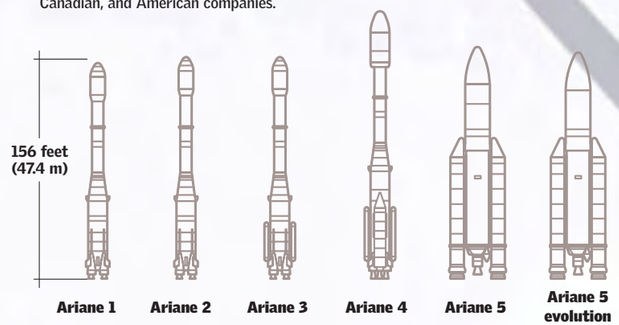
EUROPEAN SPACE AGENCY

Founded	1975
Members	17
Annual investment	3,000 million euros
Employees	1,900

Europe in Space

The ESA was formed as a single organization in 1975 by the fusion of the European Space Research Organization (ESRO) and the European Launcher Development Organization (ELDO). It carried out important missions, such as Venus Express, Mars Express, and Ulysses (with which NASA also participated). Twenty-two percent of the ESA's annual budget goes into the construction of launch vehicles.

THE ARIANE FAMILY
The development of the Ariane rocket made the ESA a leader in the space-launch market. Ariane was chosen for satellites from Japanese, Canadian, and American companies.



Russian Missions

After the initial successes with small satellites, where the effect of weightlessness was tested on animals, the Soviet Union, like the United States, began to develop programs for launching human beings into space. The first astronaut to orbit the Earth, at an altitude of 196 miles (315 km), was Yury Gagarin in 1961. He was the sole crew member of the Russian spacecraft Vostok 1. Gagarin orbited the Earth in his capsule, which was lifted into orbit by the SL-3 rocket and which had an ejection system for the cosmonaut in case of emergency.

Russians in Space

In Vostok 1 the cosmonaut had practically no control over the spacecraft, which was controlled remotely by Soviet engineers. The spacecraft consisted of a spherical cabin weighing 2.46 tons with a diameter of 7.5 feet (2.3 m). The single-person cabin was mounted on the module, which contained the rocket engine. Yury Gagarin's reentry was done with parachutes.

THE FIRST
On board Vostok 1, Gagarin was the first person to go into space. In 1961 he orbited the Earth at an altitude of 196 miles (315 km).

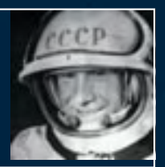
Yury Gagarin
1934-68
The Russian cosmonaut helped in promoting Russian astronautics. He died in a routine flight, on board a MiG-15 jet.

THE FIRST WOMAN
She traveled into space on board the Vostok 6 in 1963. During that mission, she flew 48 orbits around the Earth in 71 hours of flight.

Valentina Tereshkova
(b. 1937)
Tereshkova was a parachute jumping enthusiast. It was not until 19 years later that another woman became a cosmonaut.

A WALK IN SPACE
Leonov was the first to perform a space walk. In March 1965 the spacecraft Voshkod 2 carried him to outer space.

Aleksey A. Leonov
(b. 1934)
In 1953 he joined the Air Force and in 1959 began training for spaceflight. In 1975 he commanded the Apollo-Soyuz mission.



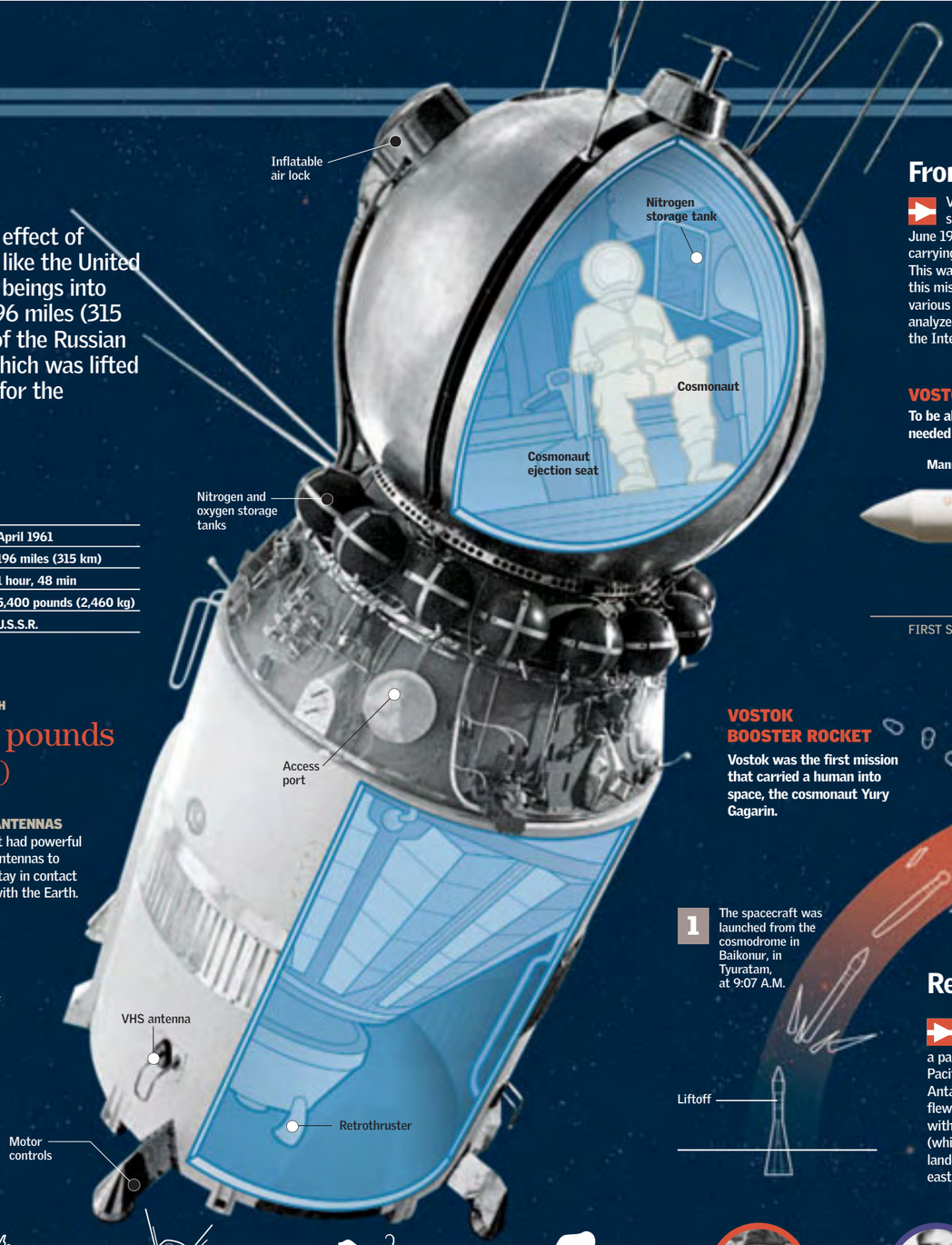
VOSTOK 1

Launch	April 1961
Orbital altitude	196 miles (315 km)
Orbital period	1 hour, 48 min
Weight	5,400 pounds (2,460 kg)
Organization	U.S.S.R.

WEIGHT ON EARTH
11,000 pounds
(5,000 kg)

ANTENNAS
It had powerful antennas to stay in contact with the Earth.

PART BY PART
Diagram of the Vostok with each of its components



From Russia with Love

Vostok ("east" in Russian) was a Soviet spacecraft program that put six cosmonauts into orbit around the Earth between April 1961 and June 1963. On June 16, 1963, a manned spacecraft of the series lifted off carrying the first female cosmonaut in the world, Valentina Tereshkova. This was a joint flight with Vostok 5, piloted by Valery Bykovsky. During this mission, medical and biological investigations were carried out, and various matters related to systems development of the spacecraft were analyzed. The spacecraft are still being used today, sending cosmonauts to the International Space Station.

VOSTOK PROGRAM

MISSIONS

Vostok 1	April 12, 1961
Vostok 2	Aug. 6, 1961
Vostok 3	Aug. 11, 1962
Vostok 4	Aug. 12, 1962
Vostok 5	June 14, 1963
Vostok 6	June 16, 1963

VOSTOK BOOSTER ROCKET
To be able to leave the Earth, Vostok needed a booster rocket.

VOSTOK BOOSTER ROCKET
Vostok was the first mission that carried a human into space, the cosmonaut Yury Gagarin.

Return Ticket

The flight began in Tyuratam, rising to an altitude of 196 miles (315 km). First it crossed a part of Siberia and then the entire breadth of the Pacific Ocean; it passed between Cape Horn and Antarctica, and once it had crossed the Atlantic it flew in African skies over the Congo. The capsule with Gagarin separated from the launch rocket (which continued in orbit) and began its descent. It landed in Saratov, approximately 460 miles (740 km) east of Moscow.

1957
SPUTNIK 2
On November 3 the second Soviet satellite was launched, with the dog Laika.

1958
EXPLORER 1
First American satellite to orbit the Earth. It was launched in February.

1958
NASA
The National Aeronautics and Space Administration was founded in the United States.

1959
LUNA 1
Launched by the Soviet Union in January, it came within 3,500 miles (6,000 km) of the Moon.

1959
LUNA 3
Launched in October, it took photos of the far side of the Moon.

1960
LITTLE DOGS
Strelka and Belka returned alive from a trip in orbit that lasted one day.

1961
HAM
The first chimpanzee to be sent into space on a suborbital flight

1961
VOSTOK 1
In a flight of 108 minutes, the Russian Yury Gagarin orbits the Earth.

1961
MERCURY
NASA's Alan Shepard made a suborbital flight of 15 minutes.

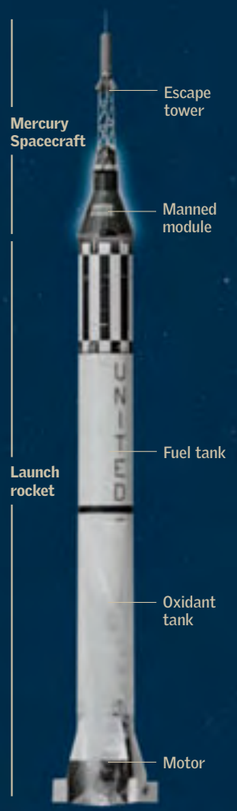
1964
GEMINI 1
The first two Gemini were launched as unmanned flights in 1964 and 1965.

1964
VOSHKOD 1
A crew of three went into space for the first time.

1965
VOSHKOD 2
Aleksey Leonov succeeded in leaving the spacecraft and carried out the first space walk.

North American Spacecraft

Over the course of the space race between the Soviet Union and the United States, the United States developed the Mercury program between 1959 and 1963. The manned capsule was small, with a volume of only 60 cubic feet (1.7 cu m). Before the first manned mission in May 1961, the American project sent three monkeys into space. The Mercury spacecraft were launched into space by two rockets: the Redstone, used for suborbital flights, and the Atlas, which was used in the five orbital flights that were achieved. Little Joe was used to test the escape tower and controls for aborting a mission.



The Mercury Experience

The development of the mission hardware was more a product of politics than of scientific intent. After the launching of Sputnik 1 in 1957 and within the framework of the Cold War, the United States made efforts to start its own space program. The development of the Mercury spacecraft was the initial step for getting the Apollo project off the ground. It was announced as a mission to fly past the Moon in 1961 but was changed by President Kennedy because he wanted an American to reach the Moon, set foot on it, and return home.

TESTING
The first sentient beings in space were animals, sent in order to ensure that humans could survive spaceflight.

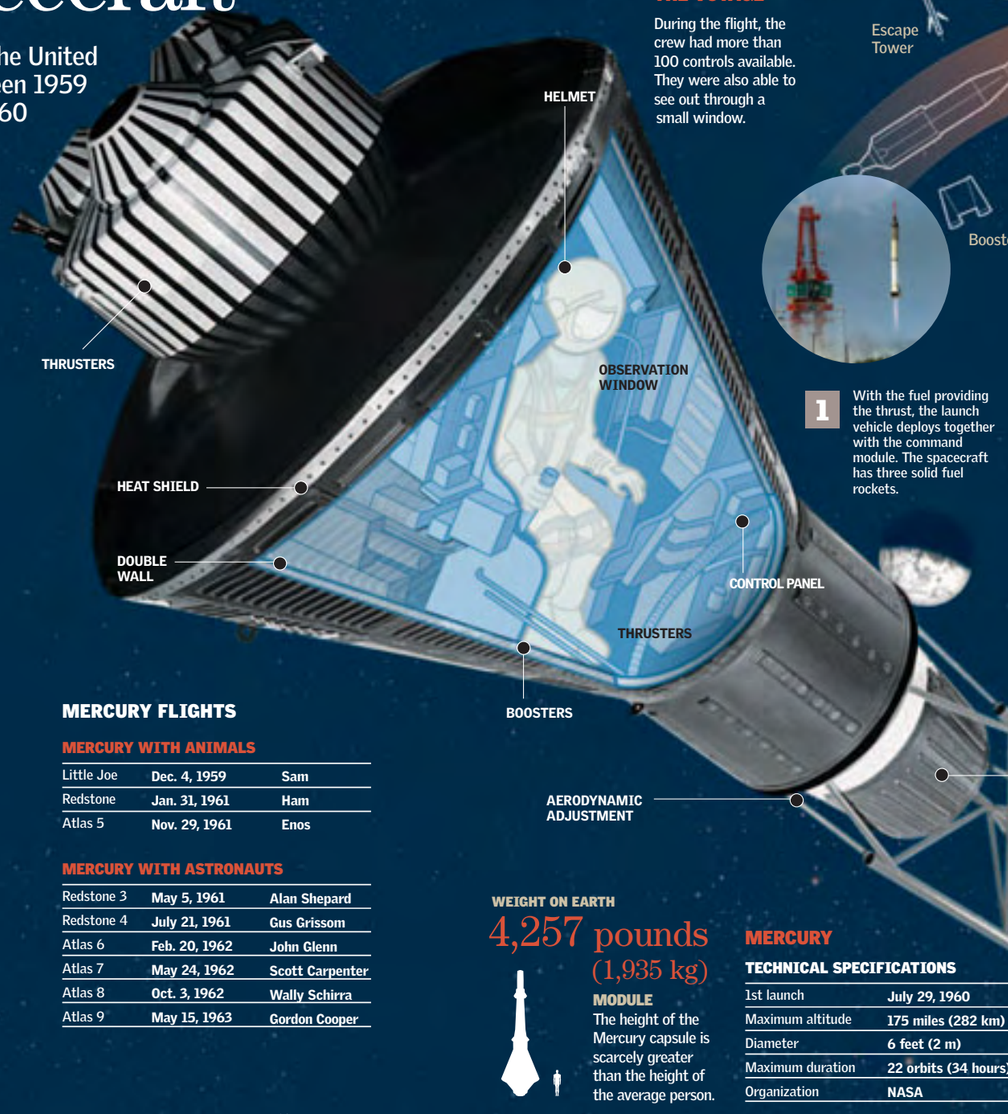
Ham
was the first monkey to fly into space. The spacecraft had sensors and remote-control instruments; Ham survived life in space without problems.

THE FIRST
On May 5, 1961, Shepard lifted off from Cape Canaveral and became the first American to fly on board a Mercury spacecraft.

Alan Shepard
1923-98
After his first voyage into space, he held important positions with NASA. In 1971 he was part of the Apollo 14 mission.

THE LAST
He was commander of the last Mercury mission, which in May 1963 completed 22 orbits and closed the operational phase of the project.

Gordon Cooper
1927-2004
Selected as an astronaut in 1959. In 1965 he carried out a Gemini mission that lasted 190 hours and 56 minutes. He retired in 1970.



THE VOYAGE

During the flight, the crew had more than 100 controls available. They were also able to see out through a small window.

1 With the fuel providing the thrust, the launch vehicle deploys together with the command module. The spacecraft has three solid fuel rockets.

2 Separating from the escape tower and the booster engine, the escape rockets ignite and the parachute system is armed.

3 The capsule turns 180°. Depending on the mission, it can complete 1–22 orbits. Then the descent begins.

4 The descent begins at an altitude of 21,000 feet (6,400 m). The capsule begins reentry. The parachutes open.

5 Before the retrieval, the pilot's parachute and the reserve parachute are detached; they fall into the sea and are retrieved.

First Voyages

The six successful flights of the Mercury mission used a solid-fuel rocket. The first, a suborbital flight in May 1961, lasted 15 minutes. Over the years, the length of space flights increased thanks to improvements in the spacecraft.

MERCURY FLIGHTS

MERCURY WITH ANIMALS

Little Joe	Dec. 4, 1959	Sam
Redstone	Jan. 31, 1961	Ham
Atlas 5	Nov. 29, 1961	Enos

MERCURY WITH ASTRONAUTS

Redstone 3	May 5, 1961	Alan Shepard
Redstone 4	July 21, 1961	Gus Grissom
Atlas 6	Feb. 20, 1962	John Glenn
Atlas 7	May 24, 1962	Scott Carpenter
Atlas 8	Oct. 3, 1962	Wally Schirra
Atlas 9	May 15, 1963	Gordon Cooper

WEIGHT ON EARTH

4,257 pounds (1,935 kg)

MODULE
The height of the Mercury capsule is scarcely greater than the height of the average person.

MERCURY

TECHNICAL SPECIFICATIONS

1st launch	July 29, 1960
Maximum altitude	175 miles (282 km)
Diameter	6 feet (2 m)
Maximum duration	22 orbits (34 hours)
Organization	NASA

1965 MARINER 4
Mariner 4 flew past Mars and took the first photos of the Red Planet.

1965 GEMINI 3
The astronauts Virgil (Gus) Grissom and John Young began the manned flights of this program.

1965 DOCKING
Gemini 6 and 7 succeeded at completing a rendezvous and docking in space. Gemini was the preceding project to Apollo.

1966 LUNA 9
On February 3 the first landing on the Moon took place. Photos were taken and sent back to Earth.

1966 SURVEYOR 1
The first American Moon landing on June 2. More than 10,000 high-resolution photos were transmitted.

1966 LUNA 10
In April the Soviet Union deployed another satellite that sent radio signals to Earth.

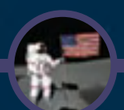
1966 APOLLO PROGRAM
The Apollo program began in February 1966 with the objective of landing on the Moon.

1967 TRAGEDY
In January three astronauts died in a fire during a routine test of the Apollo program.

1967 SOYUZ 1
The Soviet program also experienced a fatal accident. On April 24, Vladimir Komarov died when his spacecraft crashed while landing.

1968 APOLLO 8
The Saturn V is used for the first time as a booster. Apollo 8 orbits the Moon 10 times in six days.

1969 SOYUZ 4 AND 5
The Russian space program successfully docks two spacecraft as Gemini had done.



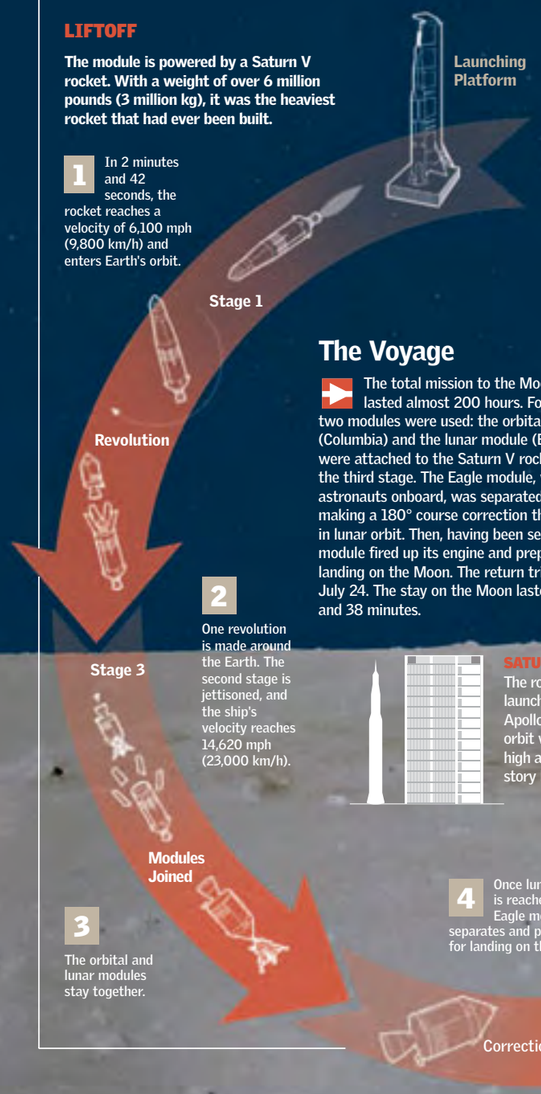
1969 APOLLO 11
The United States reaches its objective. Edwin Aldrin and Neil Armstrong walk on the Moon.

A Giant Leap

The acceleration of the space race between the United States and the Soviet Union reached its height when President Kennedy's words set the goal of landing on the Moon before the end of the 1960s. In meeting that goal in 1969, a human being for the first time in history walked on the Moon. The mission took over a week, including the trip and the stay on the Moon. It was the first launch to use two boosters: one for leaving Earth to get to the Moon and the other to return from the Moon. Neil Armstrong was the first person to leave a human footprint and place a U.S. flag in outer space.

LIFTOFF

The module is powered by a Saturn V rocket. With a weight of over 6 million pounds (3 million kg), it was the heaviest rocket that had ever been built.



1 In 2 minutes and 42 seconds, the rocket reaches a velocity of 6,100 mph (9,800 km/h) and enters Earth's orbit.

2 One revolution is made around the Earth. The second stage is jettisoned, and the ship's velocity reaches 14,620 mph (23,000 km/h).

3 The orbital and lunar modules stay together.

4 Once lunar orbit is reached, the Eagle module separates and prepares for landing on the Moon.

The Voyage

The total mission to the Moon and back lasted almost 200 hours. For the voyage, two modules were used: the orbital module (Columbia) and the lunar module (Eagle). Both were attached to the Saturn V rocket until after the third stage. The Eagle module, with two astronauts onboard, was separated after making a 180° course correction that placed it in lunar orbit. Then, having been separated, the module fired up its engine and prepared for landing on the Moon. The return trip began on July 24. The stay on the Moon lasted 21 hours and 38 minutes.

SATURN V

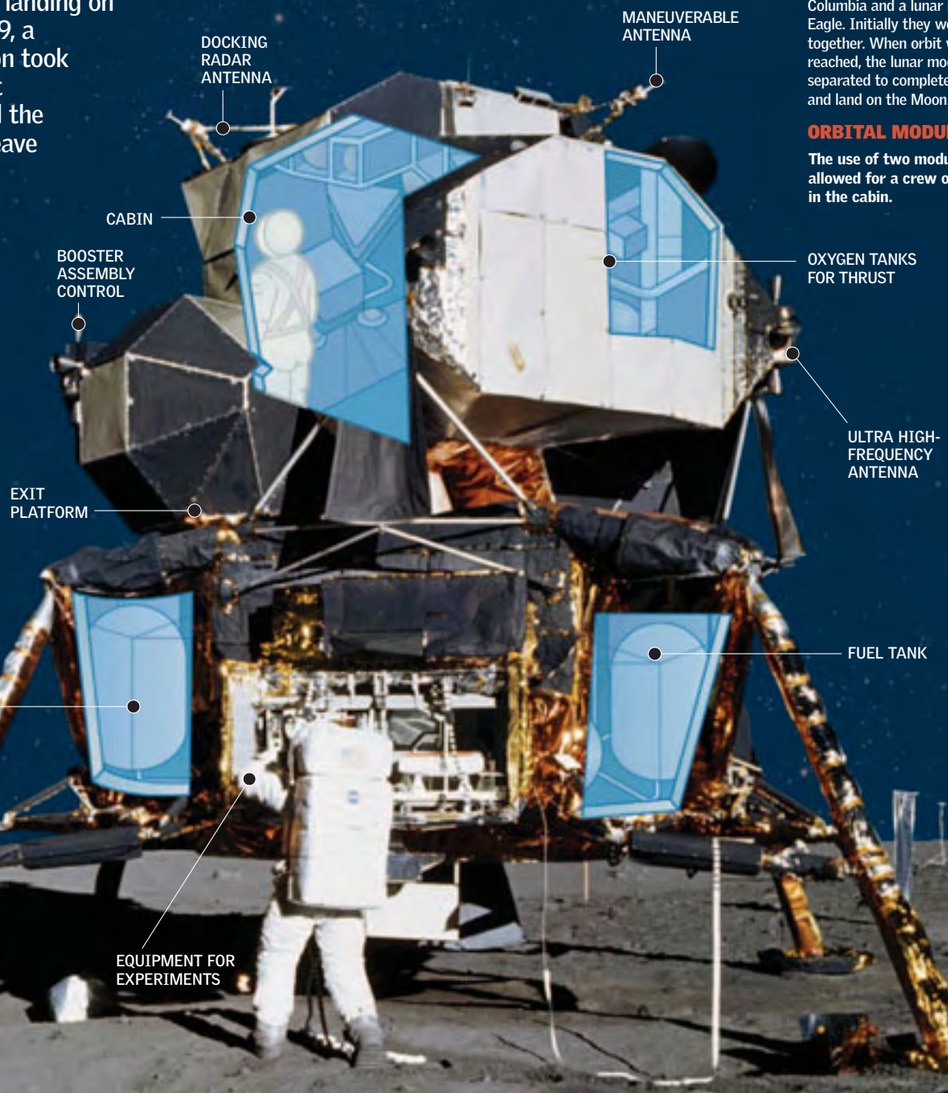
The rocket that launched Apollo into orbit was as high as a 29-story building.

LUNAR MODULE EAGLE

was divided into two sections, one for ascent and one for descent. It was coupled to the orbital module during the ascent and descent.

WEIGHT ON EARTH

54,000 pounds (24,500 kg)



LM-5 EAGLE

Landing	July 20, 1969
Height	21 feet (6.5 m)
Cabin volume	235 cubic feet (6.65 cu m)
Crew	2
Organization	NASA

ENORMOUS EAGLE

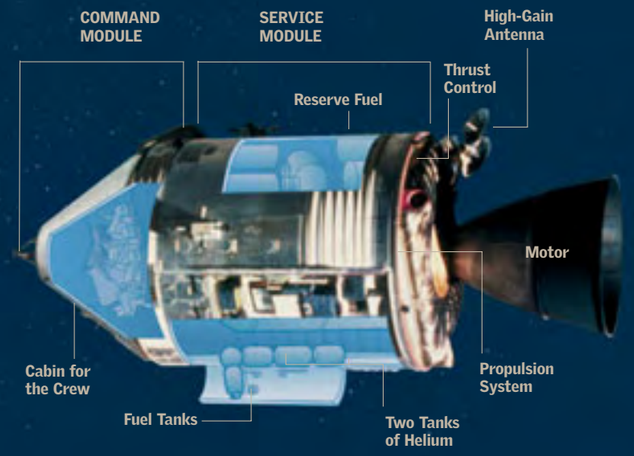
The astronaut is just over one half as tall as the leg of the module.

The Modules

The Apollo 11 mission had a spacecraft divided into two parts: the command module Columbia and a lunar module, the Eagle. Initially they were joined together. When orbit was reached, the lunar module separated to complete its descent and land on the Moon.

ORBITAL MODULE

The use of two modules allowed for a crew of two in the cabin.



CSM-107 COLUMBIA

Launch	July 16, 1969
Height	36 feet (11 m)
Diameter	12.8 feet (3.9 m)
Cabin volume	220 cubic feet (6.2 cu m)
Crew	3
Organization	NASA

WEIGHT ON EARTH

66,000 pounds (30,000 kg)

The Crew

The three members of the crew were men who already had much experience at NASA. They were all part of the Gemini program, a very important preparation for landing on the Moon and walking on its surface. Armstrong and Aldrin were the first human beings to set foot on the Moon. Collins orbited around the Moon at an altitude of 69 miles (111 km).

Neil Armstrong
(b. 1930)
carried out his first mission on board Gemini 8 in 1966. He was the first person to set foot on the Moon. He retired from NASA in 1971.

Michael Collins
(b. 1930)
was the third astronaut to carry out a space walk with the Gemini 10 mission. He was the command module pilot of the Columbia.

Edwin Aldrin
(b. 1930)
took part in the Gemini 13 training mission and was the second man to set foot on lunar soil.

The Moon Without Secrets

Six Apollo missions were able to land on the lunar surface. Apollo 13, because of an oxygen-tank explosion, flew to the Moon but did not make a landing. Through the intelligence and expertise of the astronauts onboard, it was able to return to Earth safely. With the success of these missions, the Moon was no longer unreachable. A dozen men were able to walk on the gray, crunchy lava soil strewn with craters. Each one of these voyages, besides bringing back data, encouraged the development of space science and increased the desire to carry out other missions to different locations of the solar system.

The Apollo Missions

The Apollo program began in July 1960. An important modern technological triumph, it succeeded in putting the United States ahead in the space race. Six missions made landings: Apollo 11, 12, 14, 15, 16, and 17. The Apollo lunar module was the first spacecraft designed to fly in a vacuum without any aerodynamic capabilities.

TWENTY-ONE CHOSEN
Apollo included seven missions designed to land on the Moon, with a total of 21 astronauts. Six missions completed landings, and 12 astronauts walked on the Moon's surface.

740 pounds
(336 kg)

LUNAR MATERIAL
The samples of lunar rocks turned out to be similar to those in the Earth's mantle.

15.5 miles
(25 km)

DISTANCE TRAVELED
The total distance traveled by the Lunar Rover in the Apollo 15, 16, and 17 missions

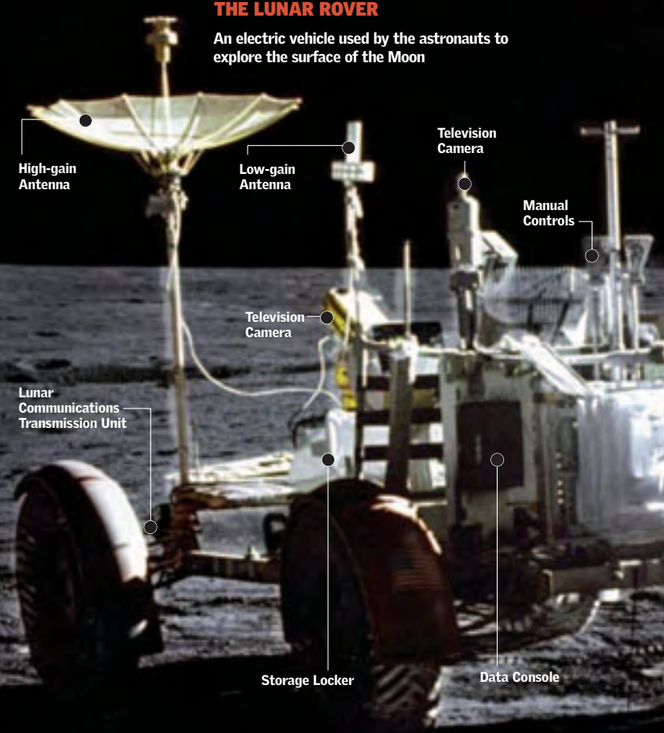
301:51'50"

STAY
The duration of the Apollo 17 mission, the longest, was almost 302 hours.

HAPPY ENDING
The Apollo-Soyuz mission ended the space race to the Moon.

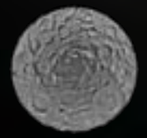
THE LUNAR ROVER

An electric vehicle used by the astronauts to explore the surface of the Moon



The Lunar Orbiter

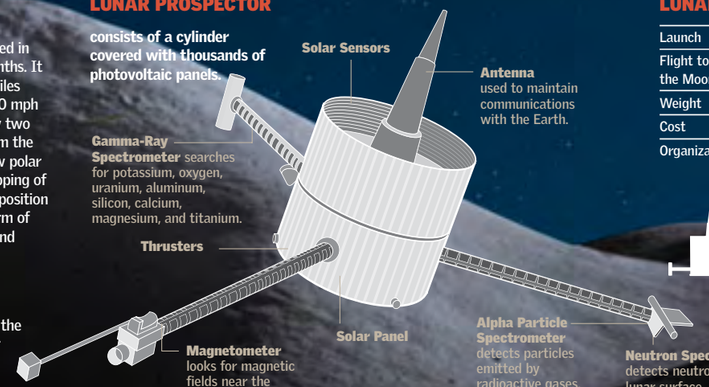
The Lunar Prospector was launched in 1997 and was in space for 19 months. It orbited the Moon at an altitude of 62 miles (100 km), traveling at a velocity of 3,400 mph (5,500 km/h), completing an orbit every two hours. This allowed it to obtain data from the surface. Its objective was to attain a low polar orbit of the Moon, which included a mapping of the surface, reconnaissance for the composition and possible deposits of water in the form of ice, and measuring the lunar magnetic and gravitational fields.



LUNAR POLE
Images taken by the Lunar Prospector

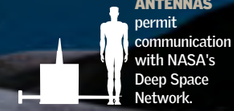
LUNAR PROSPECTOR

consists of a cylinder covered with thousands of photovoltaic panels.



LUNAR PROSPECTOR

Launch	January 1998
Flight to the Moon	105 hours
Weight	650 pounds (295 kg)
Cost	$63 million
Organization	NASA



ANTENNAS
permit communication with NASA's Deep Space Network.

End of the Apollo Program

After six landings on the Moon, the Apollo program was terminated. Apollo 18, 19, and 20 were canceled for budgetary reasons. The program had put the United States in the lead of the space race.

LUNAR ROVER

Launch	July 1971
Length	10.2 feet (3.10 m)
Width	3.7 feet (1.14 m)
Velocity	10 mph (16 km/h)
Organization	NASA

ANTENNA
High-gain, in the form of an umbrella on the Lunar Rover

WEIGHT ON EARTH
406 pounds
(209 kg)

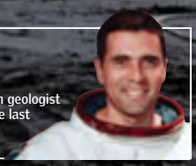
WEIGHT ON THE MOON
77 pounds
(35 kg)

APOLLO 13
The pilot of the unfortunate Apollo 13 mission, which was aborted because of an explosion on board the service module

James A. Lovell, Jr.
(b. 1928)
was the backup commander for the Gemini 4 flight and command pilot of Gemini 7 and 12.

SCIENTIST
The only civilian on the Moon. He traveled on board Apollo 17 and was the first geologist to work on the Moon.

Harrison Schmitt
(b. 1928)
North American geologist who flew on the last Apollo mission



APOLLO-SOYUZ
Russian cosmonaut Leonov was part of the Apollo-Soyuz test project in which the two craft remained docked for seven days.

Aleksey Leonov
(b. 1934)
was born in Siberia. During the Voshkod 2 mission, he was the first person to walk in space.

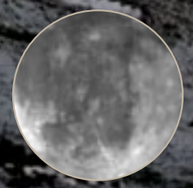
APOLLO MISSIONS

1970 APOLLO 13
The explosion of the liquid-oxygen tank of the service module forced an early return of the crew: James Lovell, Fred Haise, and John Swigert.

1972 SAMPLES
During the last lunar Apollo mission, the Apollo 17, the astronauts Eugene Cernan and Harrison Schmitt drove over the Moon in the Lunar Rover and took rock samples from the surface.

1975 APOLLO-SOYUZ
The spacecraft Apollo and the Soviet Soyuz docked in space in the first and historic joint mission between NASA and the Soviet Space Agency. It was the last Apollo mission.

LATER MISSIONS



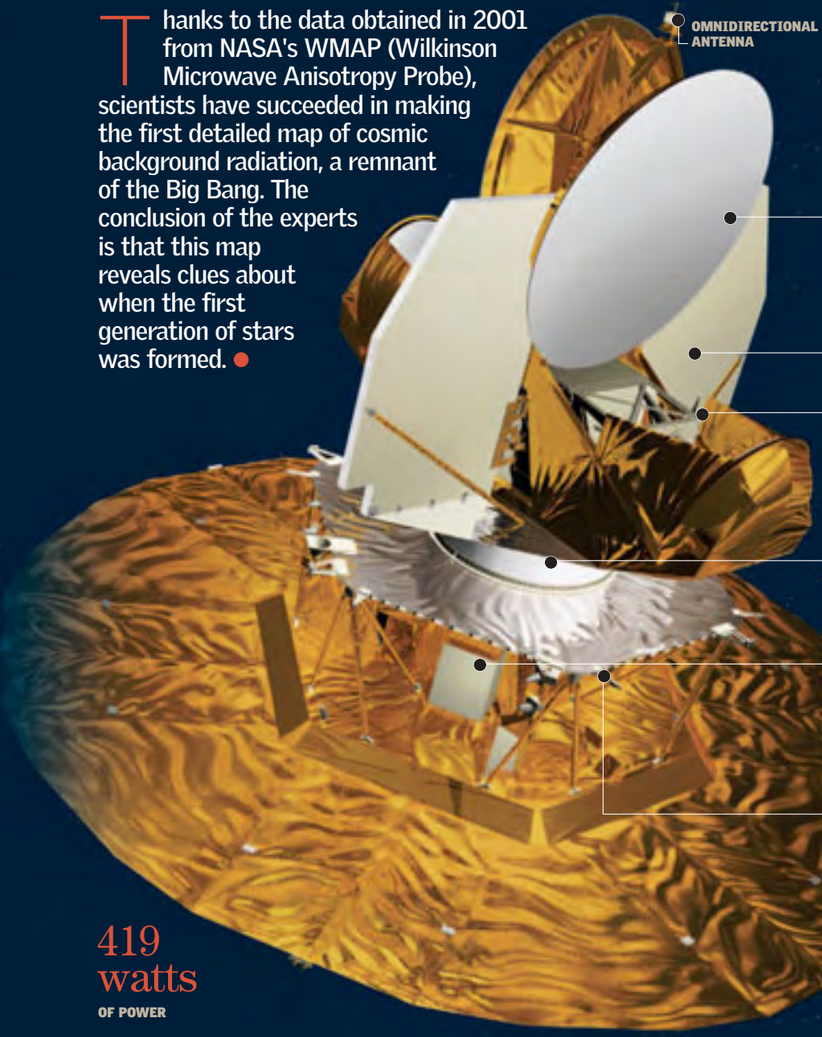
1994 CLEMENTINE
The spacecraft Clementine orbited the Moon and mapped its surface. It was also used to obtain radar data on the unlit craters near the Moon's south pole.

2003 SMART
The ESA launched Smart 1, its first unmanned spacecraft, with the Moon as its destination. Its purpose was to analyze unexplored regions and to test new technologies, such as solar ionic propulsion.

2008 LRO
NASA will launch a rocket carrying the Lunar Reconnaissance Orbiter to the south pole of the Moon to look for water that could be used on future missions.

Echoes of the Past

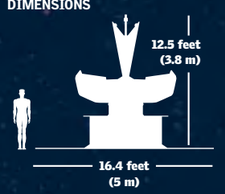
Thanks to the data obtained in 2001 from NASA's WMAP (Wilkinson Microwave Anisotropy Probe), scientists have succeeded in making the first detailed map of cosmic background radiation, a remnant of the Big Bang. The conclusion of the experts is that this map reveals clues about when the first generation of stars was formed.



WMAP

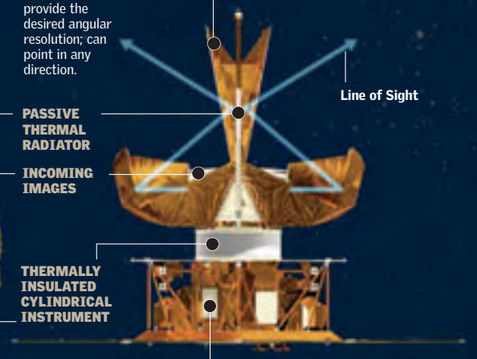
Launch	June 30, 2001
Useful life	27 months (3 months for travel and 24 for observation)
Cost	$150 million
Organization	NASA

DIMENSIONS



ITS PARTS

PROFILE VIEW



419 watts
OF POWER

1,850 pounds (840 kg)
WEIGHT ON EARTH

Observation

To be able to observe the heavens, the probe is located at the point called Lagrange L2, which is 900,000 miles (1.5 million km) from the Earth. This point provides a stable orbit far from the influence of the Earth. Sun shields protect its instruments, which always point away from the Sun. WMAP observes the heavens in several stages and measures temperature differences between various regions of the cosmos. Every six months it completely covers the entire sky, which makes it possible to compare different maps to check data consistency.

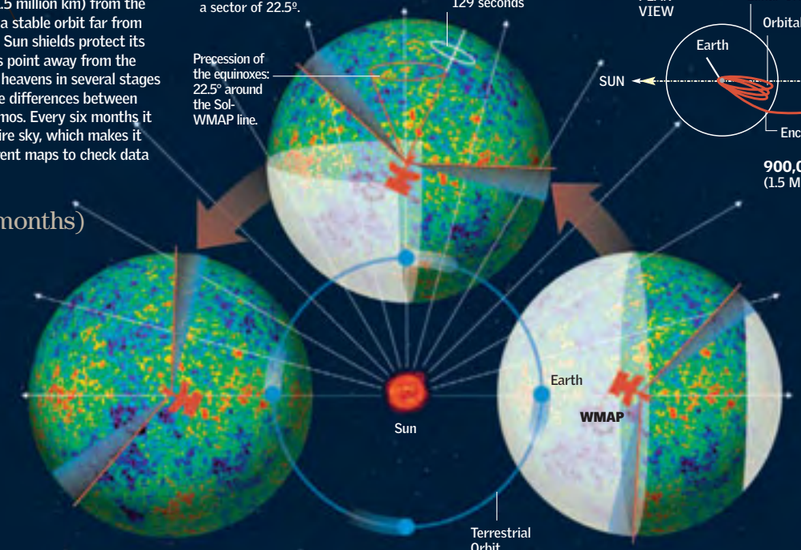
Day 90 (3 months)

The probe has completed coverage of one half of the sky. Each hour it covers a sector of 22.5º.

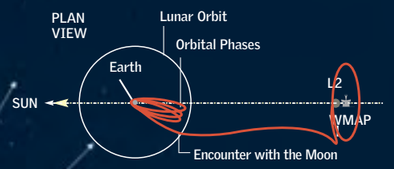
Day 180 (6 months)

The whole sky has been mapped. This is repeated four more times.

The purpose of observing the entire sky every six months is to obtain redundancy in the data gathered over two years. Then the maps can be compared to test their consistency.



WMAP TRAJECTORY
Before heading for point L2, the probe makes a flyby of the Moon to get a gravity boost toward L2.



900,000 MILES
(1.5 MILLION KM)

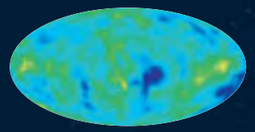
Day 1

Because it can focus on the sky in two directions simultaneously, WMAP is capable of observing a large portion of the sky every day.

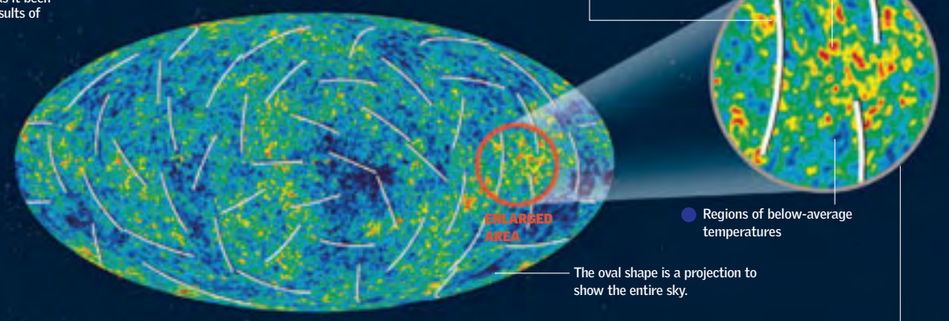
Every 24 hours, WMAP observes 30 percent of the sky.

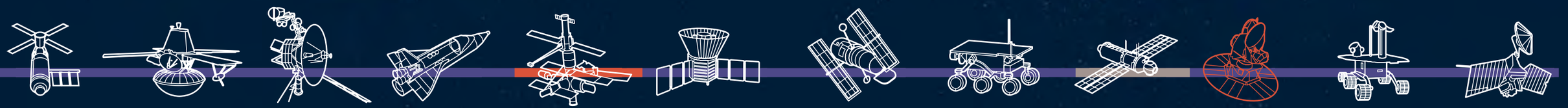
THE MAP
The details provided by WMAP are unprecedented. The various colors of the regions in the detailed map of the sky correspond to very slight differences in temperature in cosmic background radiation. This radiation, the remains of the Big Bang, was discovered in the 1960s, but only recently has it been possible to describe it in detail. The latest results of WMAP show polarized temperature zones.

COBE, the Predecessor
The results obtained by COBE in 1989 set the stage for the future. The resolution is lower, so much less detail is visible.



MOST RECENT SUCCESSES
In a photograph of March 31, 2006, polarized zones are visible in different areas of the universe.





1973 SKYLAB
The launching of the first American space station, Skylab

1976 VIKING
American satellite, takes photos of the surface of Mars

1977 VOYAGER 1 AND 2
Fly by Jupiter in 1979 and Saturn in 1980.

1981 SPACE SHUTTLE
The first manned mission was conducted with the shuttle *Columbia*.

1986 MIR
The first phase of the Russian space station Mir was successfully put into orbit.

1989 COBE
First results concerning the cosmology of the universe.

1990 HUBBLE
One of the most powerful telescopes was put into orbit.

1997 PATHFINDER
The probe released a robot that took photographs on the surface of Mars.

1998 ISS
The first module of the International Space Station is launched.

2001 WMAP
WMAP is launched to obtain the most precise data about the universe.

2004 SPIRIT
The robot, together with its twin Opportunity, reached the surface of Mars.

2005 MRO
Launched in 2005, the probe found traces of water on Mars.

Flying Through Space

SPACE SHUTTLE
The spacecraft developed by NASA can be reused after satellites have been lifted into space and put into orbit.

DEFYING GRAVITY 28-29
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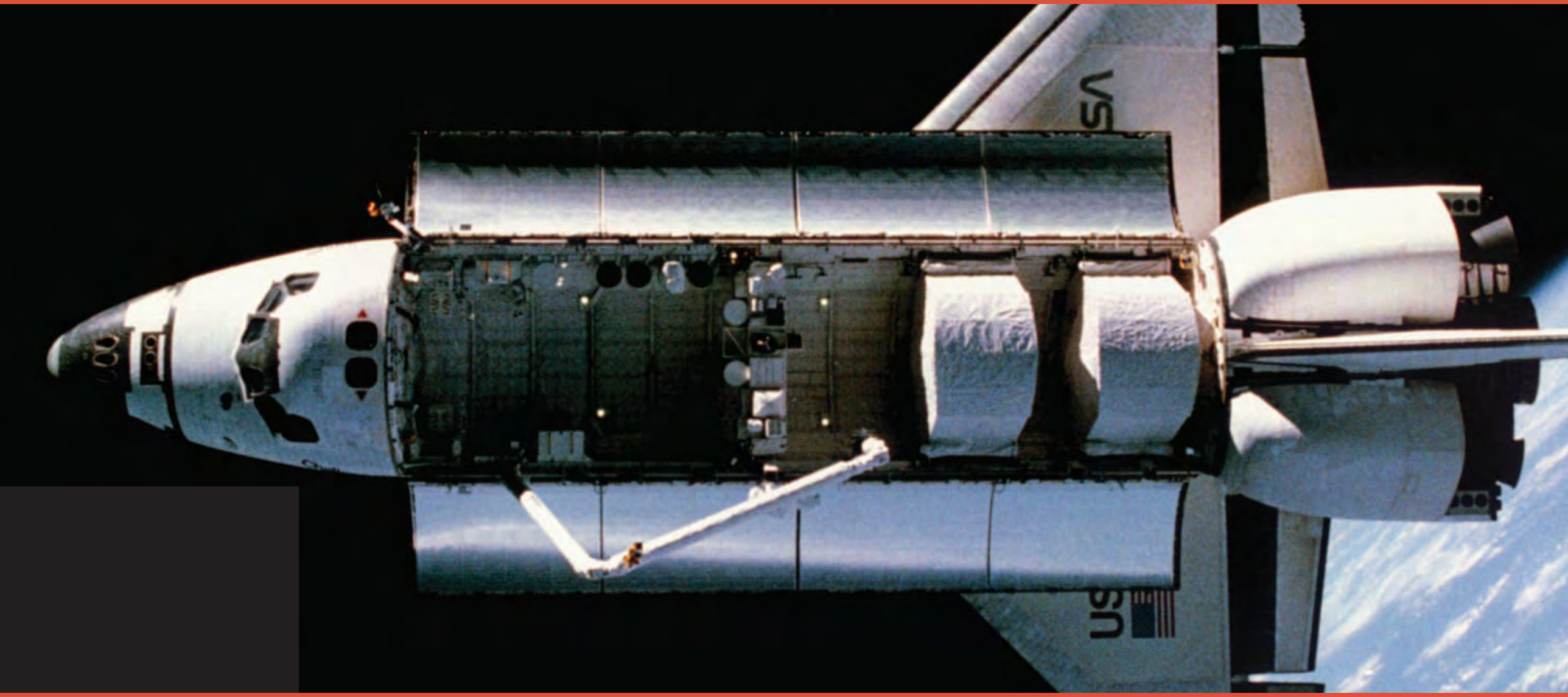


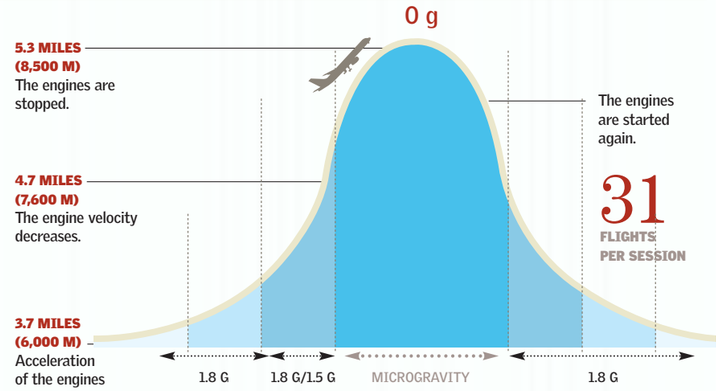
With space vehicles that have ever more capabilities, humans have attained many goals in space, such as making new discoveries about the origin and structure of the other planets. Beginning in 1981 the space shuttle became a key component in astronautics. Life onboard the shuttle is still difficult, and there are still many problems to be solved. However, the future of the human species over the long term is in space, and there is no choice but to follow that path. Like our ancestors, who immigrated to new regions of the planet to survive and prosper, we have a destiny that will take us away from the Earth to find new places to live. ●

Defying Gravity

The human body is suited for conditions under Earth's gravity. Therefore, if the force of gravity increases or decreases, the body feels a distinct, unfamiliar sensation. It causes a decrease in heartbeat; muscles become weaker and bones lose calcium. Engineers and medical doctors have investigated how humans can survive long periods where there is little gravity without causing the body to atrophy. Orbiting laboratories have been built to experiment with zero gravity on Earth.

Parabolic Flight

To achieve microgravity, a C-135 aircraft ascends at an angle of 47° until the pilot shuts off the engines and the plane begins its free fall by following a parabolic trajectory. During this phase, everything in the airplane floats, both equipment and people, because they are in a weightless condition. Such flights are organized by NASA, ESA, and RSA (the Russian Space Agency).



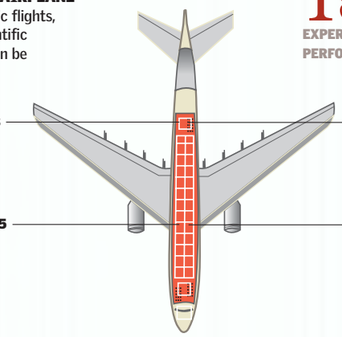
Microgravity

Gravitation is the universal force of attraction between two bodies. It depends on two principal factors: mass and distance. The greater the mass, the greater will be the attraction; on the other hand, with greater distance, the force of gravity is less. A spacecraft in orbit is essentially constantly falling around the Earth, and astronauts aboard do not feel the force of gravity even though they are being pulled by the Earth's gravity. This condition of seeming weightlessness is called a microgravity environment.

LIQUIDS
disperse in the air during conditions of microgravity.

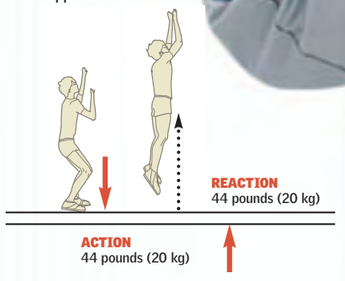
WITHIN THE AIRPLANE
During parabolic flights, nine to 15 scientific experiments can be performed.

15
EXPERIMENTS PERFORMED



WEIGHTLESSNESS
A body floats in space.

ACTION AND REACTION
Newton's third law says that when one body exerts a force on another, the second one exercises an equal force on the first in the opposite direction.

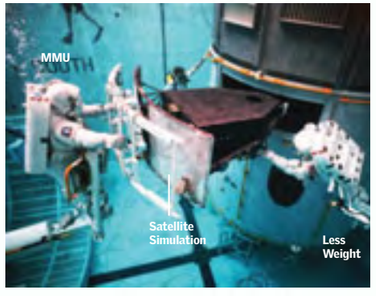


LEGS
During weightlessness, an astronaut's legs get thinner from lack of exercise, and the muscles atrophy.

GRAVITATIONAL ASSISTANCE
Some spacecraft take advantage of the gravitational force of the planets so that they can increase their speed to get to their destination. This is the case with the spacecraft Cassini, among others.

Water: Another Method for Simulating Weight Reduction

Other methods of training for the astronauts make use of a gigantic swimming pool in which an environment can be created to simulate working in microgravity. In the Johnson Space Center a simulator was installed, completely underwater, which allowed the mission crew that was to be sent to repair the Hubble telescope to test what the working conditions inside the space shuttle would be.



Point of Departure

Spacecraft launching sites typically meet one or more optimal criteria. For example, choosing a location close to the Equator makes it easier to put a spacecraft into orbit. Moreover, a number of coastal areas have been chosen, because they are more accessible for the transport of the goods needed to build the launch vehicles. The danger of an accident during launch must also be taken into account. Therefore, sites have been chosen in areas with low-density population, such as Cape Canaveral, Florida.

Vehicle Assembly Building

The spaceport has an immense building for the preparation and assembly of rockets and of the external shuttle tank. The dimensions of the building are impressive: 525 feet (160 m) high, 715 feet (218 m) long, and 387 feet (118 m) wide. The orbiter travels on top of the crawler-transporter from this building to the launch pad.

ASSEMBLY BUILDING

CRAWLER-TRANSPORTER

LAUNCHER PLATFORM

ROTATING SERVICE STRUCTURE
has a height of 189 feet (57.6 m) and moves in a semicircular path around the shuttle.

LIGHTNING RODS
The mast protects people, the shuttle, and the other platform components from lightning. It is located in the upper part of the fixed structure and is 348 feet (106 m) tall.

FIXED SERVICE STRUCTURE
The structure is 246 feet (75 m) high and divided into 12 floors. It has three arms that connect it to the shuttle.

ORBITER ACCESS ARM

PROPULSION ROCKETS

WHITE ROOM
Exclusively for astronauts. From here they go to the shuttle.

Fixed Service Structure

This steel giant is located at the launch pad. It consists of fixed and rotating structures. Atop the transport caterpillar, the mobile launch platform brings the space shuttle to this location.

ROTATING SERVICE STRUCTURE
protects the shuttle while the contamination-free fuels are being pumped into the tanks.

ELEVATOR
When the astronauts arrive at the launch pad, they ride the elevator to a facility called the white room. From there, they enter the shuttle.

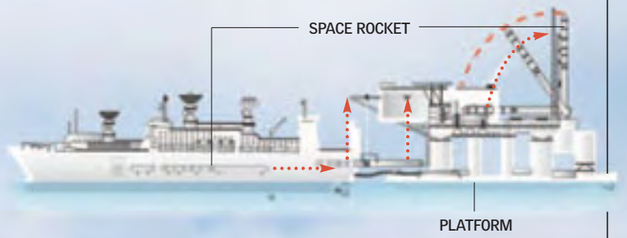
TAIL SERVICE MAST
These structures connect the platform with the spacecraft. They provide oxygen and hydrogen to the external tanks.

130 ft (40 m)

CRAWLER-TRANSPORTER
The orbiter sits on top of two caterpillar tracks and is carried to the launch pad. A system of laser rays precisely guide it as it moves at 2 mph (3.2 km/h).

Floating Platform

Earth-based launching platforms are very expensive. For this reason, some countries have developed floating launch platforms. At sea it is much simpler and safer to pick a location at the Equator, where the Earth's rotational velocity is the greatest, an advantage for putting space missions into orbit.



1 MOUNTING
A rocket is built on an assembly barge 660 feet (200 m) long.

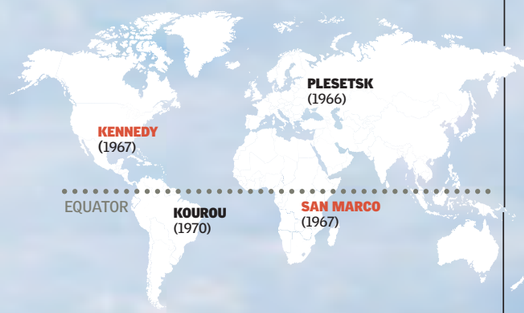
2 TRANSFER
The rocket is transferred to the launching platform Odyssey.

3 STORAGE
The rocket is stored until launch. The assembly barge leaves the location.

OTHER LAUNCHING BASES

The preference to use locations close to the Equator for spaceports has an explanation. The speed of rotation of the Earth's surface is greatest at the Equator, and vehicles launched near the Equator can take advantage of that speed to help reach orbit.

FIRST LAUNCHES FROM THE MOST IMPORTANT BASES

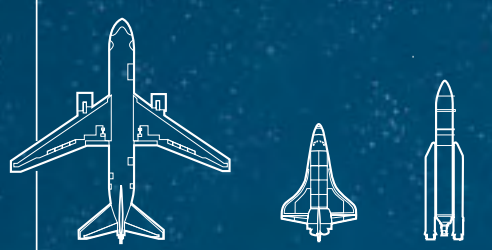


The Rockets

Developed in the first half of the 20th century, rockets are necessary for sending any kind of object into space. They produce sufficient force to leave the ground together with their cargo and in a short time acquire the velocity necessary to reach orbit in space around the Earth. On average, more than one rocket per week is sent into space from somewhere in the world.

ARIANE 5

First operational flight	Oct. 11, 1999
Diameter	16 feet (5 m)
Total height	167 feet (51 m)
Booster rocket weight	610,000 pounds (277,000 kg) each (full)
Geosynchronous payload	15,000 pounds (6,800 kg)
Organization	ESA

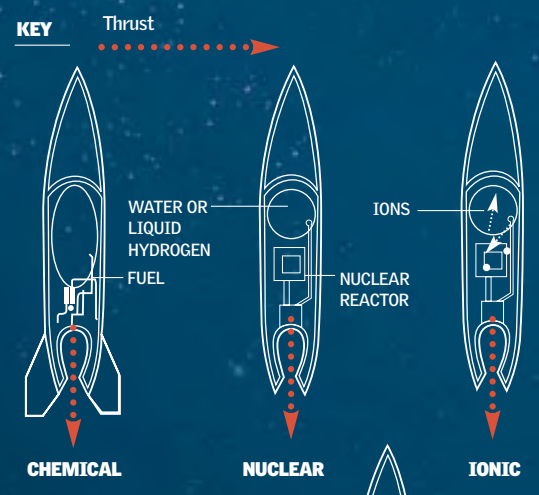


1,645,000 pounds (746,000 kg)

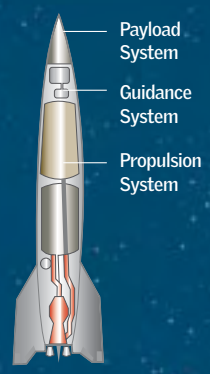
WEIGHT OF ARIANE 5

THERMAL INSULATION
To protect the combustion chamber from high temperatures of the burning fuel, the walls are sprayed with rocket fuel. This process manages to cool the engine off.

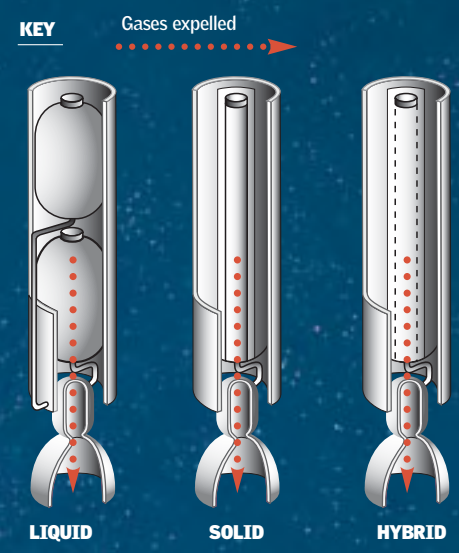
TYPE OF ROCKET DEPENDING ON ITS PROPULSION
Rockets with chemical propellants are the most common. Their thrust comes from the exhaust produced through combustion. For propulsion in space, an ion drive can be used to produce an exhaust of accelerated ions (electrically charged atoms). The use of nuclear energy has been studied as a possible source of energy for heating a gas to produce an exhaust.



COMPONENTS

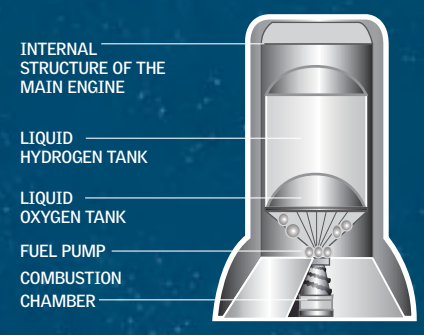


ACCORDING TO THE FUEL TYPE THEY USE, THESE WOULD BE CONSIDERED CHEMICAL (FUEL) ROCKETS.
In liquid-fuel rockets, hydrogen and oxygen are in separate containers. In solid-fuel rockets, they are mixed and contained in a single cylinder.



Engine Operation

Before liftoff, the fuel is ignited. The boosters ignite only if the ignition of the main engine is successful. The rocket lifts off, and two minutes later the boosters are extinguished, their fuel completely consumed. The main engine remains attached until its fuel is used up, and it is then jettisoned.



How It Works

To do its job, the rocket must overcome gravity. As it rises, the mass of the rocket is reduced through the burning of its fuel. Moreover, because the distance from the Earth increases, the effect of gravity decreases.

1926
On March 16, Robert Hutchings Goddard launched the first liquid-fueled rocket in the United States.

1942
V2 rockets were being built by the Germans for military use. They were the first rockets to be built on a large scale.

1961
The Soviet rocket Vostok 1 lifts the first astronaut, Yury Gagarin, into space; he orbits the Earth at an altitude of 196 miles (315 km).

1969
The rocket Saturn V sends a man to the Moon on the Apollo 11 mission. The giant rocket is more than 330 feet (100 m) high.

1988
The powerful rocket Energia puts a prototype Soviet space shuttle, the Buran, into orbit.

1999
After two failed attempts in 1996 and 1998, the Ariane 5 achieves its first successful commercial flight.

Launch Sequence

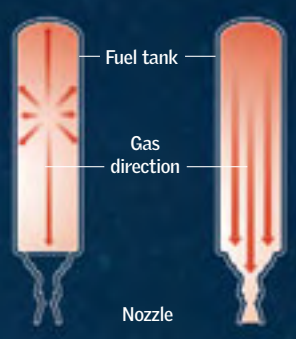
Scarcely 50 years have elapsed since the first spaceflights. Nevertheless, access to space—whether for placing satellites into orbit, sending probes to other planets, or launching astronauts into space—has become almost routine and is a good business for countries that have launch capabilities. Preparations for launch begin with the assembly of the rocket, followed by its placement on a launch pad. When its engines are ignited, the rocket rises into the atmosphere. Once the atmosphere has been left behind, less thrust is needed. For this reason, rockets consist of two or more stages stacked on top of each other. Booster rockets are typically used to produce greater initial thrust.

Bound for Space

HOW IT FLIES

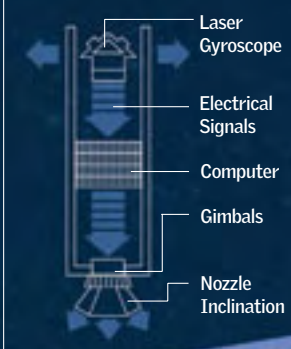
The hot gases produced by the burning fuel push in all directions.

As the gases escape through the open nozzle, they generate an opposing force.



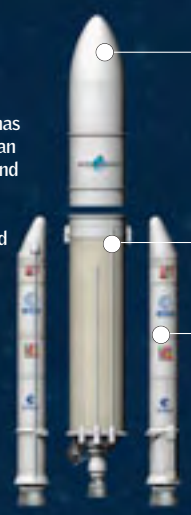
FLIGHT GUIDANCE

The rocket's guidance computer uses data from laser gyroscopes to control the inclination of the nozzles, directing the rocket along its proper flight path.



STAGES

The Ariane 5 has a main stage, an upper stage, and two booster rockets. The main stage and booster rockets are ignited at launch.



Final phase

The work of the upper stage begins. The upper-stage rocket is the only rocket not used on the launching pad. Instead it is used to insert the payload into its proper orbit. The rocket can be reignited after it is shut down and can burn for a total of 19 minutes.

00:10:00

The main stage, ignited at the end of the countdown, separates and falls back to Earth. Its supply of liquid hydrogen and oxygen has been used up.

Fairing

The fairing is jettisoned when the air becomes so thin that wind no longer poses any danger to the payload.

Launch Countdown

The countdown for the Ariane 5 typically lasts six hours. At the end of the countdown, the launch begins with the ignition of the main stage's liquid-fuel engine. Seven seconds later the two solid-fuel boosters are ignited. Before the boosters' ignition, the flight can be aborted by shutting down the main stage.

-06:00:00
The launch countdown begins.

-04:30:00
The tanks begin to be filled.

-01:00:00
Mechanical reinforcements are made.

-00:06:30
The automatic launch sequence starts.

00:00:00
The main-stage engines are ignited.

00:00:07
The solid-fuel boosters are ignited. The rocket begins to lift off 0.3 second later.

Detachment

Explosive bolts separate the boosters from the main stage and the main stage from the second stage.

00:02:10
At 200,000 feet (60,000 m) the solid-fuel boosters separate and fall to the ocean in a secure area.

363 feet (111 m)

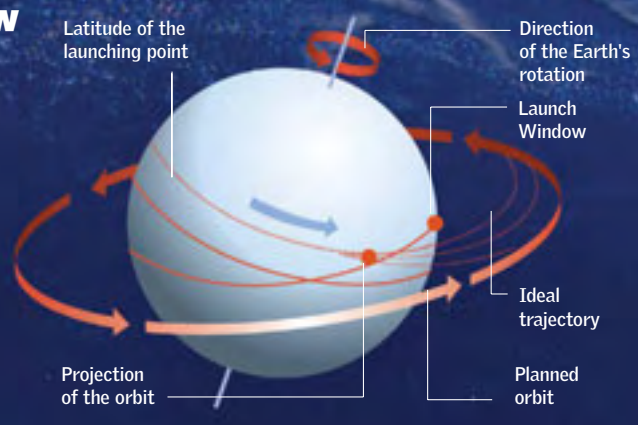
The height of the Saturn V, the largest rocket ever launched. It was used in the late 1960s and early 1970s to take astronauts to the Moon. During launching it could be heard 90 miles (150 km) away.

Solid-fuel boosters

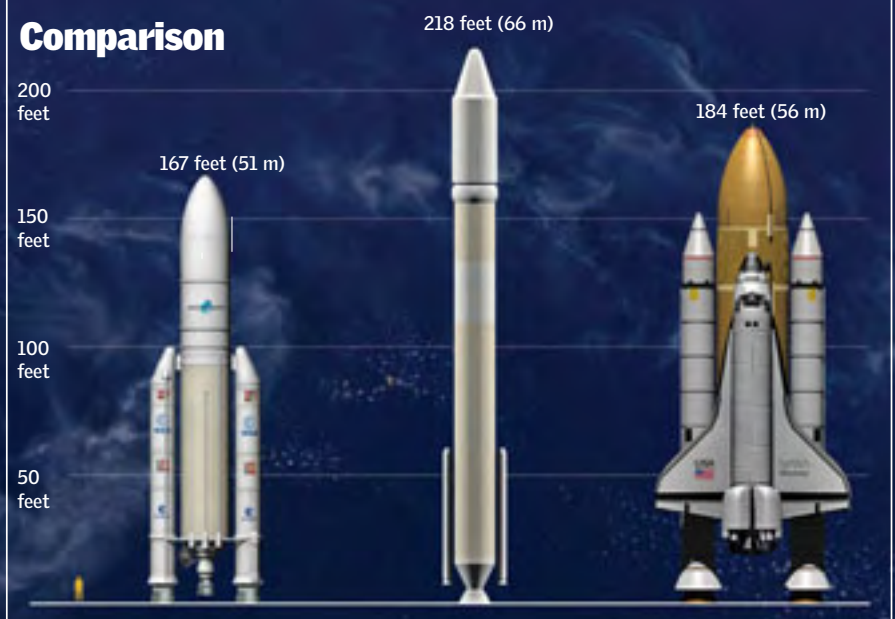
provide 90 percent of the initial thrust needed to launch the Ariane 5. The boosters are 102 feet (31 m) high and contain 525,000 pounds (238,000 kg) of fuel. Once the fuel is used up, the boosters are separated from the main stage, 130 seconds into the flight.

Launch Window

Rockets must be launched at predetermined times, which depend on the objective of the launch. If the objective is to place a satellite into orbit, the latitude of the launched rocket needs to coincide with the trajectory of the desired orbit. When the mission involves docking with another object in space, the launch window might fall within only a few minutes.



Comparison



ARIANE 5	DELTA IV M+	SPACE SHUTTLE
Weight at launch: 822 tons (746 t)	Weight at launch: 330 tons (300 t)	Weight at launch: 2,200 tons (2,000 t)
First operational flight: 1999	First operational launch: 2002	First operational launch: 1981
Maximum payload: 7.5 to 17.6 tons (6.8-16 t) depending on the desired orbit	Maximum payload: 6 to 12.9 tons (5.5-11.7 t) depending on the desired orbit	Maximum payload: 27.5 tons (25 t) into low Earth orbit.

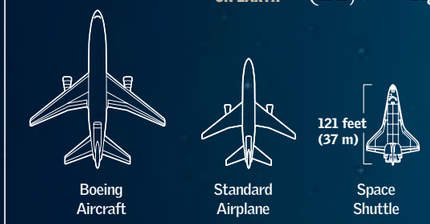
Space Shuttle

Unlike conventional rockets, the U.S. space shuttle can be reused to lift satellites into space and put them into low Earth orbit. Today these vehicles are also used to make flights to the International Space Station. The U.S. fleet has three shuttles: *Discovery*, *Atlantis*, and *Endeavour*. The *Challenger* exploded in 1986 and the *Columbia* in 2003.

TECHNICAL DATA FOR THE SPACE SHUTTLE

First launch	April 12-14, 1981
Mission length	5-20 days
Width	79 feet (24 m)
Length	121 feet (37 m)
Organization	NASA

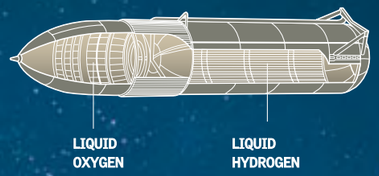
25,500 pounds (11,600 kg)
WEIGHT ON EARTH



The Cabin

The place where the members of the crew live is divided into two levels: an upper level houses the pilot and the copilot (and up to two more astronauts), and a lower level is used for daily living. The amount of habitable space inside the cabin is 2,470 cubic feet (70 cu m).

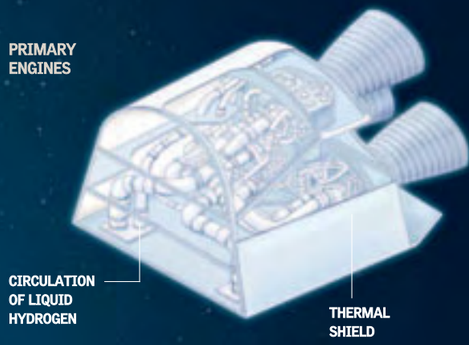
CONTROLS
There are more than 2,000 separate controls in the flight cabin, three times as many as in Apollo.



External Fuel Tank
connects the shuttle to the launch rockets. It carries liquid oxygen and liquid hydrogen, which are ignited via a tube that connects one container to the other. The tank is discarded after each voyage.

Primary Engines

There are three primary engines, which are fed by oxygen and liquid hydrogen from the external tank. Each engine has computer-based controls that make adjustments to obtain the correct thrust and mix of fuel.



ORBITAL ENGINES
provide the thrust for orbital insertion and for orbital changes required in the orbit. The engines are located on the outside of the fuselage.

WING
The wings have no function in space. They are needed for landing the spacecraft.

HATCHES
are opened when the orbiter reaches low Earth orbit. They have thermal panels that protect the spacecraft from overheating.

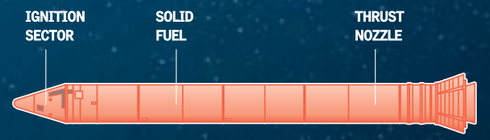
Thermal Protection

When a shuttle begins reentry from Earth's orbit, friction heats the surface to a temperature between 570 and 2,700° F (300-1,500° C). Various parts of the spacecraft must have protective layers to keep them from melting. The inner parts of the wings and the nose heat up the most.

KEY

- Ceramic fiber: temperature below 700° F (370° C)
- Silicon ceramic: 700-1,200° F (370-648° C)
- 1,200-2,300° F (648-1,260° C)-also silicon
- Metal or glass, without thermal protection
- Carbon in areas above 2,300° F (1,260° C)

Solid-Fuel Rockets
are designed to last for some 20 flights. After each flight, they are recovered from the ocean and refurbished. They carry the shuttle to an altitude of 27 miles (44 km) and are capable of supporting the entire weight of the shuttle while standing on the ground.



ORBITAL SPECIFICATIONS

Orbital altitude	190-330 miles (310-530 km)
Orbital period	97 minutes
Average orbital speed	17,200 mph (27,800 km/h)

Front View

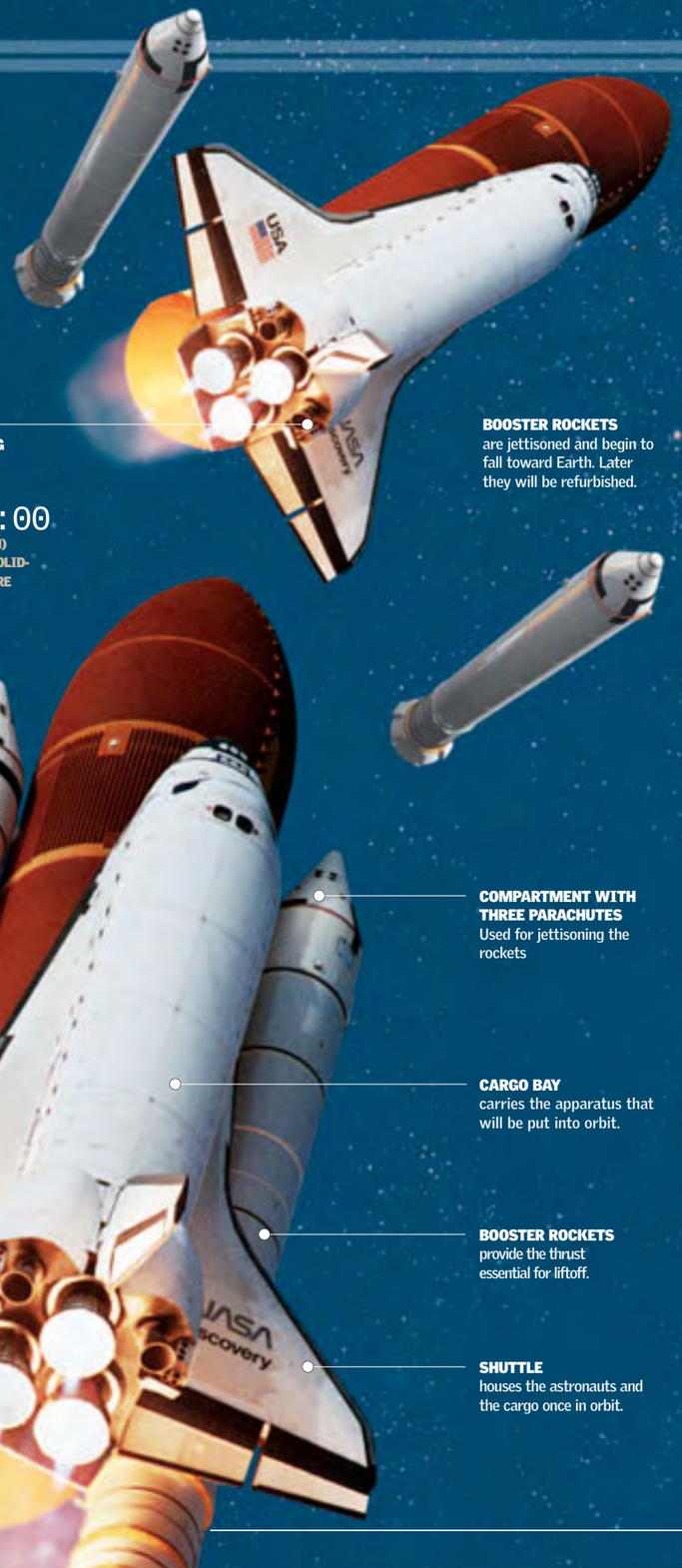
Back View

ORBITAL MANEUVERING SYSTEM

00:02:00

27 MILES (44 KM) ALTITUDE: THE SOLID-FUEL ROCKETS ARE JETTISONED.

BOOSTER ROCKETS
are jettisoned and begin to fall toward Earth. Later they will be refurbished.



00:08:00

THE EXTERNAL TANK IS JETTISONED.

EXTERNAL TANK
Its fuel is fed to the shuttle engines until just before the shuttle reaches orbit. The tank is immediately jettisoned and as it falls it burns up through atmospheric friction.

ORBITAL MANEUVERING CONTROL SYSTEM
puts the shuttle into an appropriate orbit. Depending on the mission, its altitude could be as high as 700 miles (1,100 km).

2

5-30 DAYS

ORBITS IN SPACE
Once the necessary altitude has been reached for the mission, the shuttle remains in space between 10 and 16 days. It is then oriented for the return flight to Earth.

17,400 mph
(28,000 km/h)
SPEED REACHED BY THE SHUTTLE

3

REENTRY INTO THE ATMOSPHERE
The shuttle undergoes a communications blackout because of the heated air that surrounds it.

1

00:00:00

LIFTOFF
The two solid-fuel rockets and the three main engines go into action. They burn two million pounds (900,000 kg) of propellant, and the shuttle reaches an altitude of 27 miles (44 km). The solid fuel is completely consumed.

2,200 tons
THE LIFTOFF WEIGHT OF THE SPACE SHUTTLE

EXTERNAL TANK
carries fuel to be used in liftoff.

COMPARTMENT WITH THREE PARACHUTES
Used for jettisoning the rockets

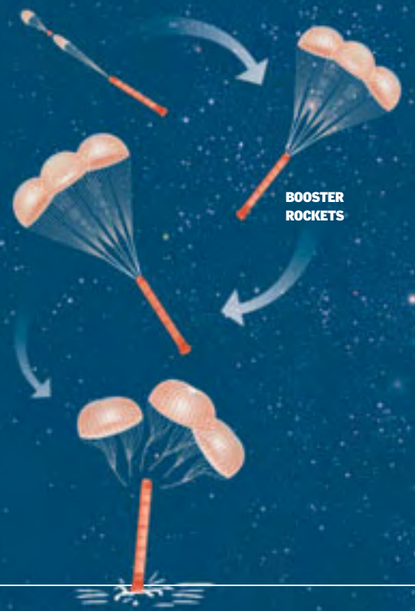
CARGO BAY
carries the apparatus that will be put into orbit.

BOOSTER ROCKETS
provide the thrust essential for liftoff.

SHUTTLE
houses the astronauts and the cargo once in orbit.

Retrieval System

Two minutes after the shuttle's liftoff, the booster rockets have burned up their fuel. They are jettisoned, and the parachutes deploy for their fall into the ocean. Later the booster rockets are retrieved by ships and refurbished.



BOOSTER ROCKETS

4

LANDING
The shuttle landing sequence is completely automatic and kicks in two minutes before returning to terra firma. It lands on a runway 3 miles (5 km) long.

20°

LANDING ANGLE

4,900° F
(1,500° C)
MAXIMUM TEMPERATURE

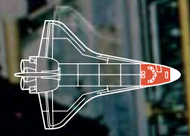
TURNS
It makes various "S" turns to reduce its velocity.

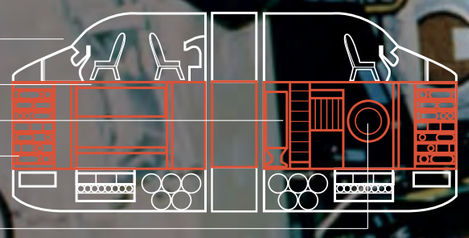
Far from Home

The experience of leaving the Earth to live in a space station or to take a trip in the shuttle is a fascinating adventure. Life in orbit requires many adjustments to survive in an environment where there is no water, air pressure, or oxygen. The crew cabin is pressurized, and water is produced electrically with oxygen and hydrogen. Food requires special packaging, and the garbage is pulverized.

Crew Cabin

The crew cabin is located at the front of the shuttle. The control deck is on the upper level, and the lower level has sleeping and living compartments as well as the hatch for entering and leaving the cabin.





Physical Ailments

The human body is accustomed to Earth's gravity. In space the astronauts experience weightlessness, floating in the spacecraft. Life in space can have undesirable effects on the body, such as bone and muscle reduction. In many cases, living in small spaces can cause psychological problems. Also, radiation from solar storms can cause severe damage.

LOSS OF CALCIUM IN THE BONES
In microgravity, the bone tissue is not regenerated but absorbed by other tissues. The loss of mass can appear as an excess of calcium in other parts of the body (for example, kidney stones).

EARPHONES help maintain communication.

CLOTHES Comfortable clothes are used during the day.

TETHER holds down the body to keep it from floating.

1 SLEEP
Once a day
The Sun rises and sets every hour and a half when the shuttle is in orbit, but the astronauts attempt to sleep eight hours once a day. They must stay tethered to keep from floating.

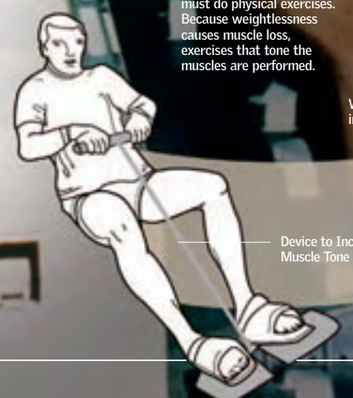
90 minutes
THE LENGTH OF A DAY IN ORBIT

2 TOILET
To go to the bathroom, a system of suction with air is used because it is impossible to use water. Baths can be taken. After a bath, the same clothes are used because there is no way to wash clothes in space.

3 FOOD
3 times a day
Every day the astronauts have breakfast, lunch, and dinner. They must bring the food to their mouths very carefully. They must drink enough water or they could begin to suffer from dehydration.

4 WORK
8 hours a day
They work four hours on Saturdays and have Sundays off. Weekdays are normal workdays. The most common tasks are scientific experiments and normal maintenance.

5 EXERCISE
2 hours a day
Every day, in order to stay in good health, astronauts must do physical exercises. Because weightlessness causes muscle loss, exercises that tone the muscles are performed.



72 72 VARIETIES OF DISHES

20 VARIETIES OF DRINKS

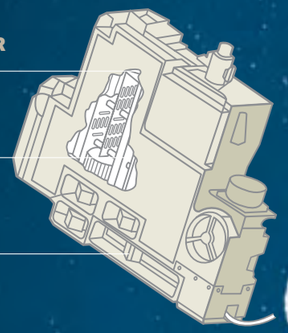
Profession: Astronaut

How do you become an astronaut? Before undertaking a mission in space, every candidate must submit to rigorous examinations since the tasks they are to perform are very delicate and risky. They must intensively study mathematics, meteorology, astronomy, and physics and become familiar with computers and navigation in space. They must also train physically to get used to low-gravity conditions in orbit and to be able to carry out repairs.

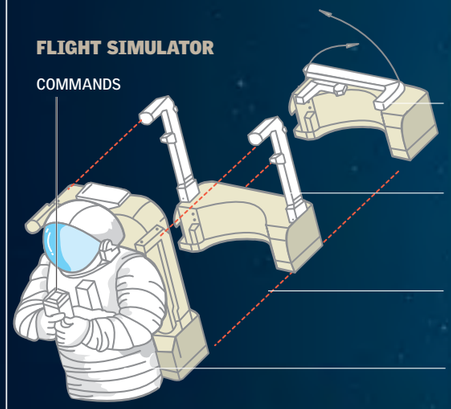
Manned Maneuvering Unit

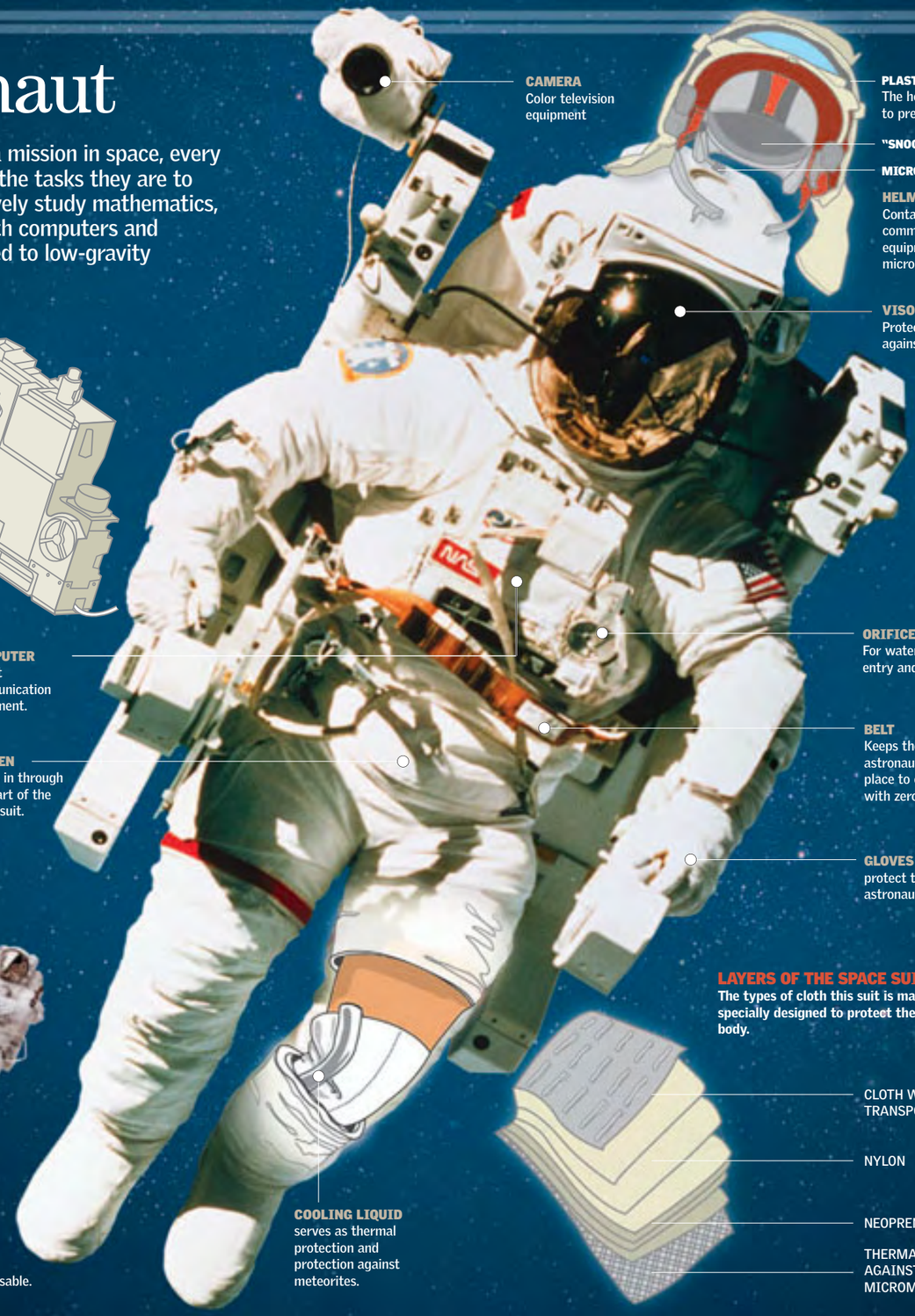
The training program is difficult and exhausting. There are daily activities in the flight simulators with specialized computers.

COMPUTER
VISOR
DIGITAL CAMERA
IMAGE CONTROLLER

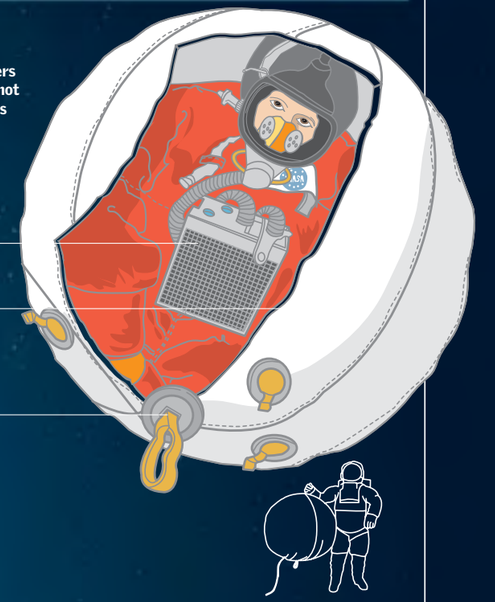


FLIGHT SIMULATOR



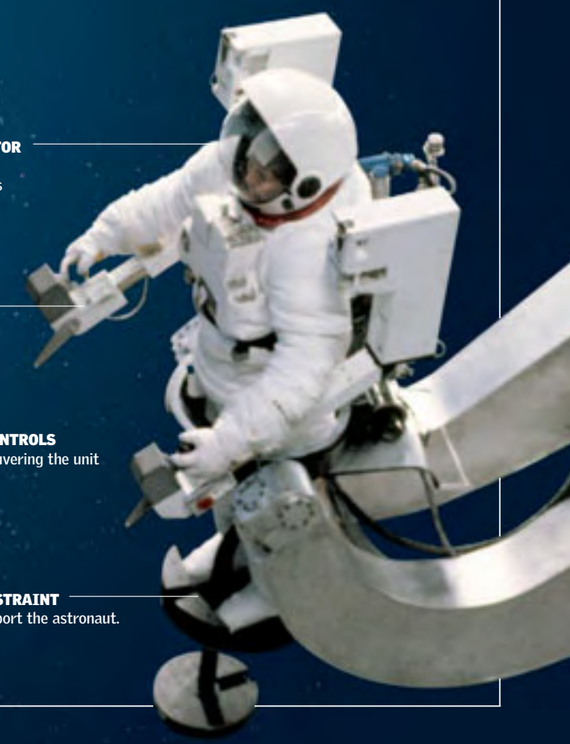


RESCUE SPHERE
is to help the members of the crew who do not have space suits. It is made of space-suit material and has its own oxygen supply.



Physical Training

This is the hardest part. To habituate themselves to the microgravity of space, the astronauts begin training in modified airplanes, where they handle equipment, eat, and drink during the moments of least gravity. The manned maneuvering unit (MMU), with which the astronauts go out of the spacecraft to make repairs in space, has an underwater model for preparatory training on Earth.



1965
The astronaut Edward White used this space suit to perform a space walk in the vicinity of the Gemini capsule.

1969
Neil Armstrong used this space suit when he performed his first historic space walk on the surface of the Moon.

1984
Bruce McCandless wore this space suit when he became the first person to carry out a space walk without being tethered to the shuttle.

1994
Space shuttle astronauts demonstrate a suit that is much more modern and reusable.

LAYERS OF THE SPACE SUIT
The types of cloth this suit is made of are specially designed to protect the astronaut's body.

Control from Earth

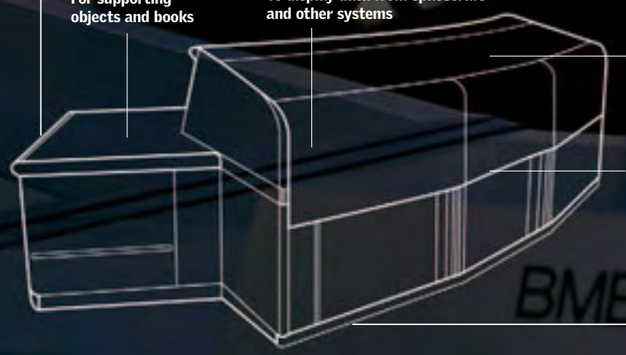
Monitoring the astronauts' activity is done from operations centers. In the United States, NASA is in charge of the manned missions from the Mission Control Center located in the Johnson Space Center in Houston. The unmanned missions are supervised from the Jet Propulsion Laboratory in Los Angeles. Utilizing telemetry technology, which makes it possible to see technical aspects in real time, the flight controllers carry out their tasks in front of consoles equipped with computers.

Houston Space Center Floor Plan

The center was used for the first time in 1964 for the Gemini 4 mission. The operations control room has an auditorium, a screen that projects the locations of tracking stations on the Earth, and another screen showing the passage of satellites in orbit. Computers control all the components of the spacecraft.

Console

The Operations Control Room consists of about a hundred consoles. The consoles form desks with an area for more than one monitor. They have drawers and counters for providing a working area.



SCREEN 1
records the location of the satellites and other objects in orbit.

ROW 3
FLIGHT DIRECTION
The countdown before liftoff is performed and the flight plan made.

ROW 4
DIRECTORATE
The lead authorities are located in the fourth row, from where they coordinate the crew's flight operations.

SPACE MAINTENANCE IS CARRIED OUT
365
DAYS A YEAR

The Big Screen

An enormous screen dominates the Operations Control Center. It gives information on the location and orbital trajectory of a spacecraft in flight as well as other data. The screen is of vital importance for the operators, because it allows for a rapid reading of information to take action efficiently and to prevent accidents.

SCREEN 2
shows the location and path of spacecraft in orbit.

24-hour days
TIME THAT THE CENTER IS OPERATING DURING MISSIONS

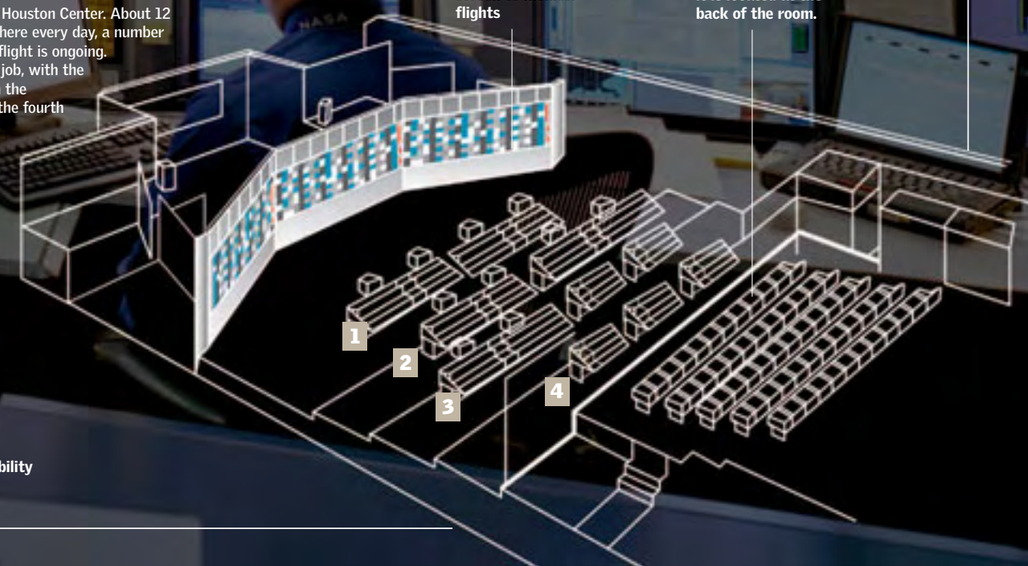
ROW 1
LIFTOFF MONITOR
Also controls the trajectory and carries out course adjustments of the spacecraft.

ROW 2
MEDICAL SECTION
The second row checks the astronauts' health and establishes communication with the crew.

Space Shuttle Control Center

It is smaller than the Houston Center. About 12 air controllers work there every day, a number that may rise to 20 when a flight is ongoing. Each worker has a different job, with the first row being the lowest in the management hierarchy and the fourth row the highest.

1. **SPACECRAFT COMMUNICATOR** maintains contact with the astronauts.
2. **FLIGHT SURGEON** checks the medical condition of the crew.
3. **FLIGHT DIRECTOR** helps the director of mission control.
4. **MISSION DIRECTOR** has the main responsibility for flight control.



Permanent Exploration

THE SPIRIT
Shown with its panels extended, Spirit is one of the robot explorers for studying Martian soil.

SATELLITE ORBITS 48-49
CUTTING-EDGE TECHNOLOGY 50-51
SPACE PROBES 52-53
MARTIAN ROBOTS 54-55
A HOME IN SPACE 56-57
SPYING ON THE UNIVERSE 58-59
SPACE JUNK 60-61

Space exploration brings scientific ideas to everyone's attention. This is beneficial because it stimulates our creativity and curiosity.

Moreover, these flights contribute to the training of a new generation of scientists. Mars has often been seen as a goal for space exploration, perhaps because of its proximity to Earth and its relatively hospitable surface. Among the probes that NASA has sent to Mars are two robots, Spirit and Opportunity, that scratched the surface of the Red Planet and sent back very interesting data—they found geologic evidence of ancient environmental conditions in which there was water and in which life could have been present. ●

Satellite Orbits

The space available for placing communications satellites is not unlimited. On the contrary, it is a finite space that could become saturated with too many satellites. Desirable locations in geostationary orbits are already reaching this situation, chock-full of television and other communications satellites. The placement of these instruments cannot be arbitrary; errors of 1 or 2 degrees in position can generate interference with neighboring satellites. The positions are regulated by the International Telecommunications Union. Geostationary satellites have the advantage of being in a fixed position with respect to the Earth's surface. In contrast, satellites in low or medium orbit require a sequence of terrestrial stations to maintain a communications link.

Different Types

The quality of the information transmitted by the satellites depends on their position relative to the Earth. The geostationary orbit (GEO), which is the most commonly used orbit today, makes it possible to provide coverage to the entire planet with only four satellites, whereas lower orbits need constellations of satellites to get total coverage. This is the case for satellites in LEO (low Earth orbit). In other cases, satellites in MEO (medium Earth orbit) typically describe elliptical orbits. A GEO satellite is in a circular orbit, and if it orbits over the Equator, it always maintains the same position with respect to the Earth.

Frequency Bands

The satellites transmit information in different frequencies depending on their function.

KA BAND
Used for instruments in space and for local multipoint transmission. The frequency range varies between 18 and 31 GHz. This band has the greatest capacity for data transmission.

L BAND
Used for the GPS system, cell phones, and digital radio. Operates in frequencies between 1.5 and 2.7 GHz. This band has the least data-transmission capacity.

K BAND
Used for television and radio transmissions. Transmits in a range between 12 and 18 GHz.

LEO ORBIT
MEO ORBIT
GEO ORBIT

GPS

ORBITAL INCLINATION 55°

LEO ORBIT

A low Earth orbit is between 125 and 1,900 miles (200-3,000 km) above the Earth. LEO has been used for telephone communications satellites because of GEO saturation. The orbits are circular and require less transmission power than other orbits. However, they require Earth-based centers to track the satellites.

SPOT

393 miles (632 km)

EARTH'S AXIS 23°

MEO ORBIT

The altitude of satellites in a medium Earth orbit (MEO) ranges from 20,500 miles (33,000 km) up to the altitude of the geostationary satellites. They generally describe an elliptical orbit. Because putting them in orbit requires more energy than for a satellite in LEO, their cost is greater.

GLONASS

ORBITAL INCLINATION 64.8°

11,800 miles (19,000 km)

GALILEO

ORBITAL INCLINATION 60°

INTELSAT

22,400 miles (36,000 km)

IRIDIUM

HUBBLE TELESCOPE

POLAR ORBIT

GEO ORBIT

The geostationary orbit (GEO) is the most common, particularly for television satellites. A satellite in a geostationary orbit orbits the Earth in 23 hours and 56 minutes. Because this equals the rotation of the Earth, the satellite remains stationary relative to the Earth's surface. A satellite in GEO orbits 22,400 miles (36,000 km) above the Earth.

EQUATORIAL ORBIT

A
INNER VAN ALLEN BELT
Its greatest concentration is about 1,860 miles (3,000 km) above the surface of the Earth.

B
OUTER VAN ALLEN BELT
Primarily between 9,300 and 12,400 miles (15,000 and 20,000 km) above the surface of the Earth

ELLIPTIC ORBIT

APOGEE
The point farthest from the Earth

PERIGEE
The point closest to the Earth

CIRCULAR ORBIT

The same distance

ORBITS	LEO	MEO	GEO
Distance from the Earth	125-1,900 miles (200-3,000 km)	1,900-22,400 miles (3,000-36,000 km)	22,400 miles (36,000 km)
Satellite cost	Low	Medium	High
Type of network	Complex	Moderate	Simple
Satellite life	3-7 years	10-15 years	10-15 years
Coverage	Short	Medium	Continuous

22,400 miles (36,000 km)
is the altitude necessary for the orbit of a satellite so that it will remain stationary with respect to the Earth's surface.

VAN ALLEN BELTS

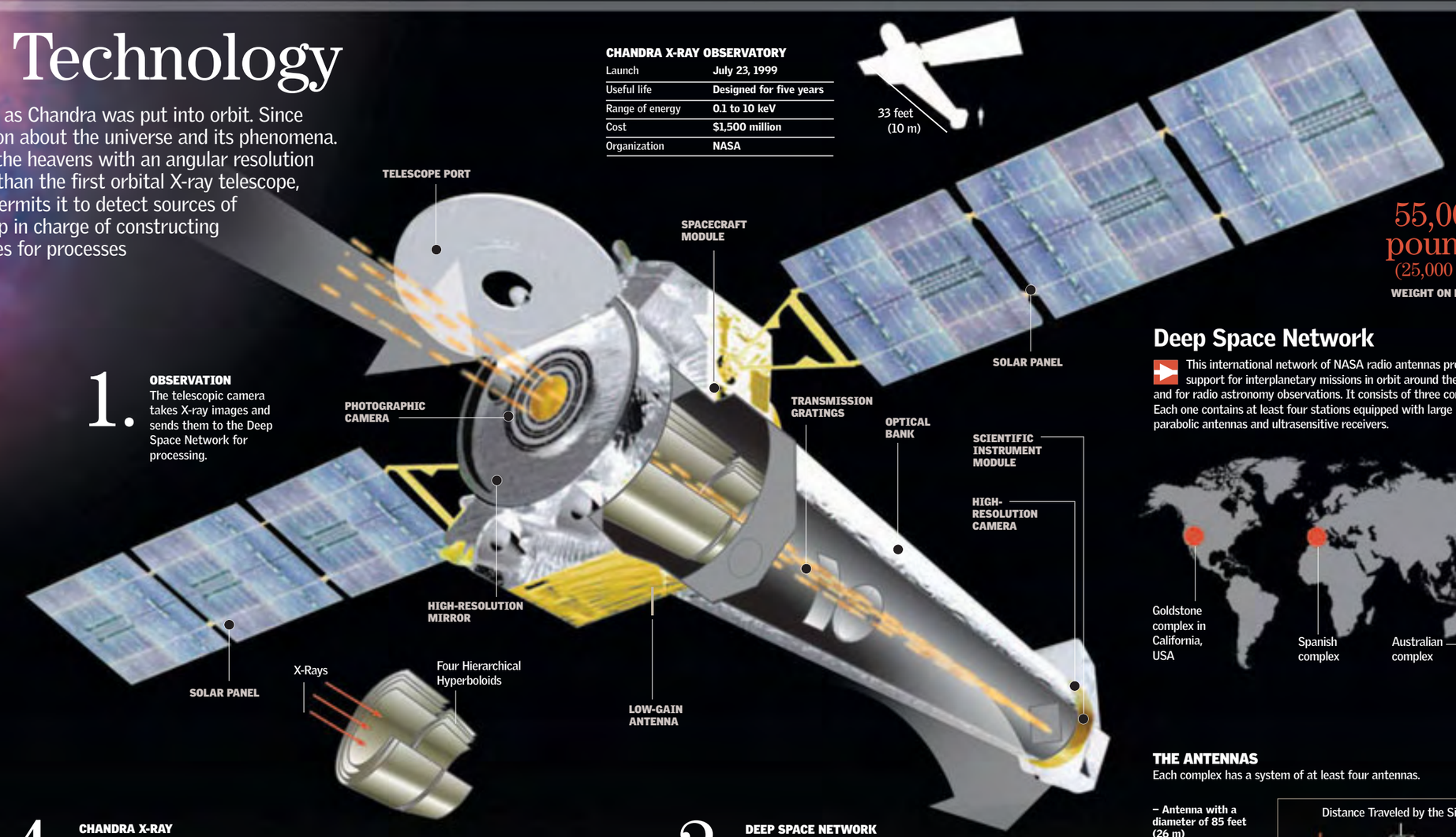
Regions of the Earth's magnetosphere where charged particles are concentrated and protons and electrons move in spirals. There are two zones of concentrated particles, the inner and outer radiation belts.

Cutting-Edge Technology

In July 1999 the X-ray observatory known as Chandra was put into orbit. Since then, it has provided important information about the universe and its phenomena. Chandra can make X-ray observations of the heavens with an angular resolution of 0.5 seconds of an arc, 1,000 times greater than the first orbital X-ray telescope, the Einstein Observatory. This characteristic permits it to detect sources of light that are 20 times more diffuse. The group in charge of constructing the X-ray telescope had to develop technologies for processes that had never been used before.

CHANDRA X-RAY OBSERVATORY

Launch	July 23, 1999
Useful life	Designed for five years
Range of energy	0.1 to 10 keV
Cost	$1,500 million
Organization	NASA



55,000 pounds (25,000 kg)
WEIGHT ON EARTH

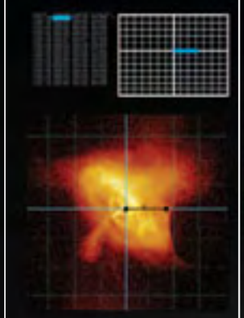
Data Transmission

The satellite system provides the structure and the equipment necessary for the telescope and the scientific instruments to operate. A propulsion system gradually puts the spacecraft into its final orbit, which is elliptical and extends far from Earth. In order to control the critical temperature of its components, Chandra has a special system of radiators and thermostats. The temperature near the X-ray mirrors has to be maintained at the proper temperature to keep the mirrors in focus. The electrical energy of the satellite comes from solar panels and is stored in three batteries.

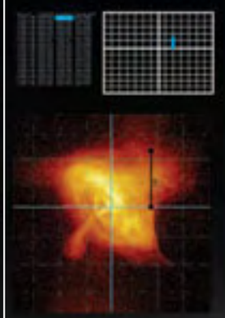
HOW IMAGES ARE CREATED

The information compiled by Chandra is transferred to tables and images with coordinates of the *x*- and *y*-axes.

1 TABLE contains the time, position, and the energy collected by Chandra during its observations.



2 *X*-AXIS Data extending horizontally on the grid



3 *Y*-AXIS Data extending vertically on the grid

1. OBSERVATION
The telescopic camera takes X-ray images and sends them to the Deep Space Network for processing.

2. DEEP SPACE NETWORK
The network is used for communicating with the spacecraft and for receiving information.

Every eight hours
Chandra contacts the Deep Space Network.

3. JET PROPULSION LABORATORY
receives information from the Deep Space Network and processes it.

4. CHANDRA X-RAY CONTROL CENTER
It is responsible for operating the observatory and receiving the images. The operators are responsible for preparing commands, determining the altitude, and monitoring the condition and the safety of the satellite.

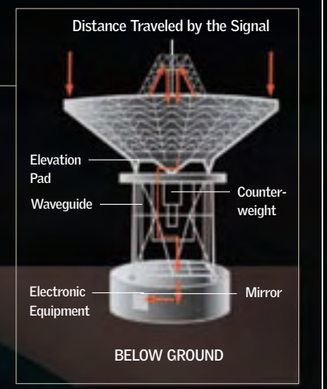
Deep Space Network

This international network of NASA radio antennas provides support for interplanetary missions in orbit around the Earth and for radio astronomy observations. It consists of three complexes. Each one contains at least four stations equipped with large parabolic antennas and ultrasensitive receivers.

THE ANTENNAS

Each complex has a system of at least four antennas.

- Antenna with a diameter of 85 feet (26 m)
- High-gain antenna with a diameter of 110 feet (34 m)
- Low-gain antenna with a diameter of 110 feet (34 m)
- Antenna with a diameter of 230 feet (70 m)



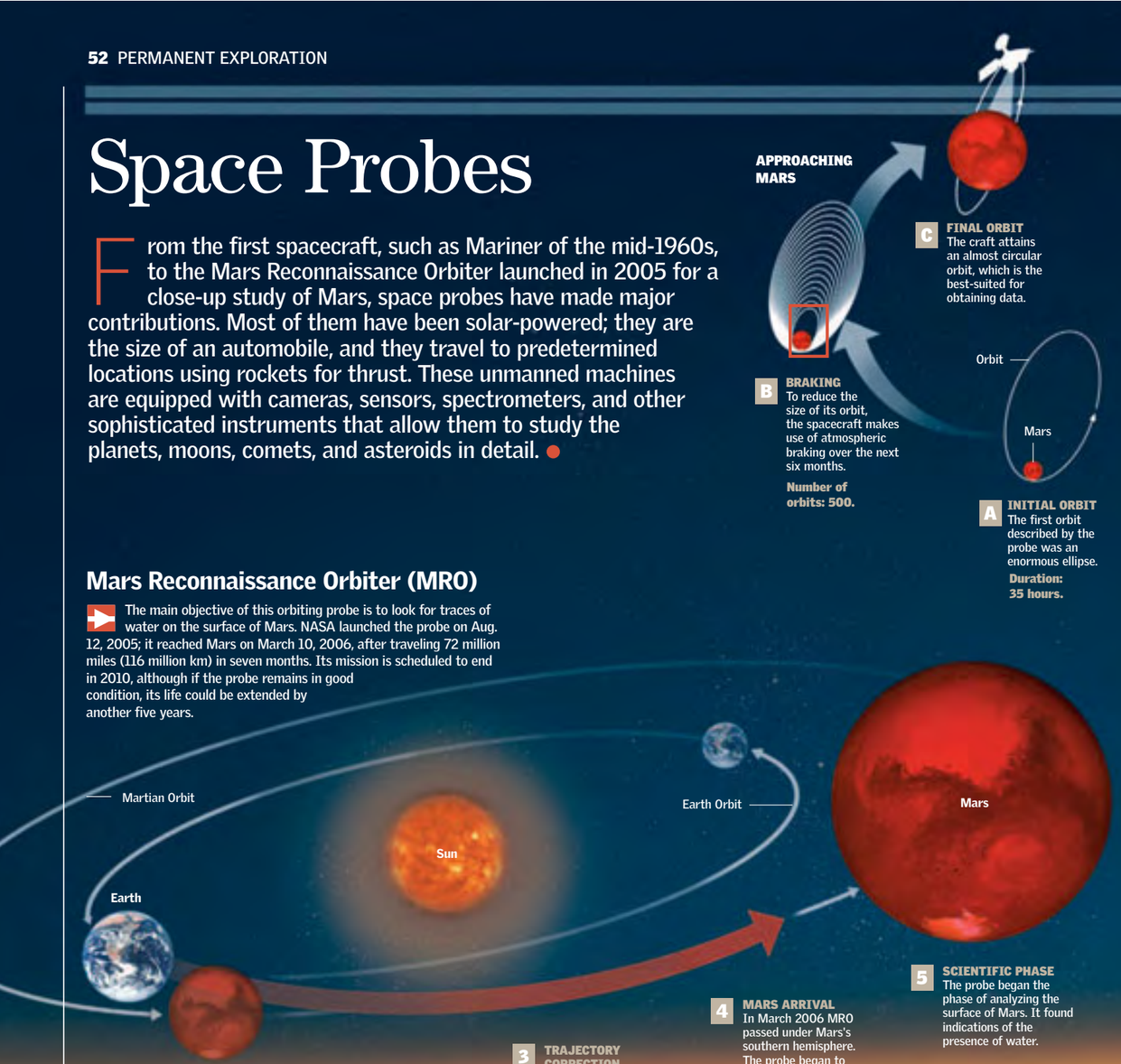
FIVE YEARS
WAS TO BE THE LIFETIME OF THE MISSION, BUT IT WAS SURPASSED.

Space Probes

From the first spacecraft, such as Mariner of the mid-1960s, to the Mars Reconnaissance Orbiter launched in 2005 for a close-up study of Mars, space probes have made major contributions. Most of them have been solar-powered; they are the size of an automobile, and they travel to predetermined locations using rockets for thrust. These unmanned machines are equipped with cameras, sensors, spectrometers, and other sophisticated instruments that allow them to study the planets, moons, comets, and asteroids in detail.

Mars Reconnaissance Orbiter (MRO)

The main objective of this orbiting probe is to look for traces of water on the surface of Mars. NASA launched the probe on Aug. 12, 2005; it reached Mars on March 10, 2006, after traveling 72 million miles (116 million km) in seven months. Its mission is scheduled to end in 2010, although if the probe remains in good condition, its life could be extended by another five years.



1 LAUNCH
Launched on Aug. 12, 2005, from Cape Canaveral

2 CRUISING FLIGHT
The probe traveled 7.5 months before arriving at Mars.

3 TRAJECTORY CORRECTION
Four maneuvers were carried out to attain the right orbit.

4 MARS ARRIVAL
In March 2006 MRO passed under Mars's southern hemisphere. The probe began to decelerate.

5 SCIENTIFIC PHASE
The probe began the phase of analyzing the surface of Mars. It found indications of the presence of water.

APPROACHING MARS

C FINAL ORBIT
The craft attains an almost circular orbit, which is the best-suited for obtaining data.

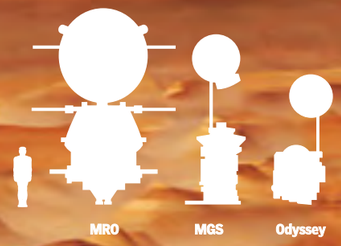
B BRAKING
To reduce the size of its orbit, the spacecraft makes use of atmospheric braking over the next six months.
Number of orbits: 500.

A INITIAL ORBIT
The first orbit described by the probe was an enormous ellipse.
Duration: 35 hours.

TECHNICAL SPECIFICATIONS

Weight with fuel	4,800 pounds (2,180 kg)
Temperature rating of the panels	Down to -390° F (-200° C)
Launch rocket	Atlas V-401
Mission duration	five years (with possible extension)
Cost	$ 720 million

2,270 pounds (1,031 kg) WEIGHT ON EARTH



72 million miles (116 million km) THE DISTANCE TRAVELED BY THE PROBE TO REACH MARS

ANTICIPATED VOLUME OF DATA TRANSMISSION

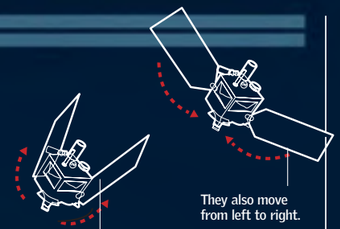
DS1 (Comets)	15 Gigabytes
Odyssey (Mars)	1,012 Gigabytes
MGS (Mars)	1,759 Gigabytes
Cassini (Saturn)	2,550 Gigabytes
Magellan (Venus)	3,740 Gigabytes
MRO (Mars)	34,816 Gigabytes

On Mars

The principal objective of the MRO is to find indications of water on the Martian surface. This could help explain the evolution of the planet. The equipment obtains high-resolution images of the surface and permits a mineral analysis. The weather on Mars is mapped daily.

HIGH-GAIN PARABOLIC ANTENNA
has a data transmission capacity 10 times greater than that of previous orbiters.

SOLAR PANELS
The principal source of energy for the probe is the Sun. The spacecraft has two solar panels with a total surface area of 430 square feet (40 sq m).



OPENING THE PANELS
They open in orbit.

3,744
THE NUMBER OF CELLS IN EACH PANEL FOR CONVERTING SOLAR ENERGY INTO ELECTRICITY

SHARAD RADAR

SOLAR PANEL

8 feet (2.53 m)

SOLAR PANEL

18 feet (5.35 m)

POWERFUL INSTRUMENT
Used together, HIRISE, CTX, and CRISM provide very good information on one particular area.

HIRISE High-resolution camera
Provides excellent views of very small objects. Gives details of geologic structures and substantially improves on the resolution of the earlier missions.

HIRISE
Mars Reconnaissance Orbiter

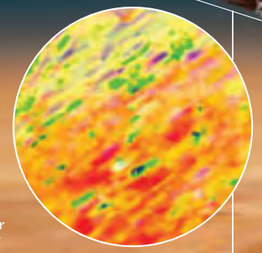
MGS
Mars Global Surveyor

MCS observes the Martian atmosphere.

MARCI provides color for the images.

CTX Context Camera
provides panoramic views of large areas. Helps to provide a context for the high-resolution images taken by HIRISE and CRISM.

CRISM Spectrometer
separates the visible light from the infrared of the images into 100 colors to identify different minerals, especially those indicating the presence of water.



HIRISE CRISM CTX

Martian Robots

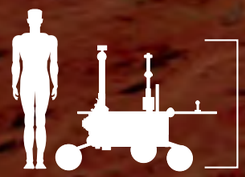
Spirit and Opportunity, the twin robots launched in June 2003 from Earth that landed on Martian soil in January 2004, were designed to travel over the surface of the Red Planet. Both vehicles are part of NASA's Mars Exploration Rovers mission. They have tools that allow them to drill into rock and take samples of the soil to analyze their chemical composition. The robots are located on opposite sides of the planet to explore two uniquely different places. They each use nine cameras.

Water and Life on Mars

The main purpose of the mission conceived by NASA was to find indications whether there had ever been water on Mars. In Spirit's first mission, it was thought that small quantities of water might have seeped into the eroded rock fragments. The rocky Martian soil, it is believed, could have been affected by the action of water. So far, there is no evidence of the existence of living microorganisms. Between ultraviolet radiation and the oxidative nature of the soil, life on Mars is not currently possible. The question that remains is whether life might have existed at some time in the past or even today deep inside the Martian subsoil, where conditions for life might be more favorable.

TECHNICAL SPECIFICATIONS

Date of landing	**Spirit: Jan. 3, 2004 Opportunity: Jan. 24, 2004**
Cost of the mission	**$ 820 million**
Progress per day	**330 feet (100 m)**
Plutonium	**Each spacecraft carries 0.01 ounces (2.8 g)**
Useful life	**More than two years**

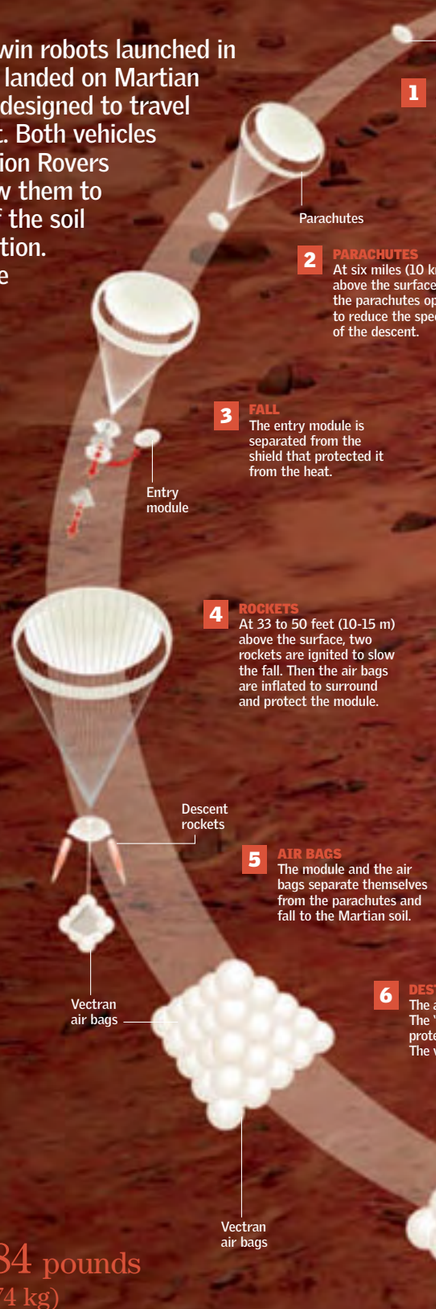


5 feet (1.50 m)

384 pounds (174 kg)
WEIGHT ON EARTH

HOW IT GOT TO MARS

The voyage to Mars lasted seven months. Once inside the Martian atmosphere, parachutes were deployed to slow the descent.



1 DECELERATION
The aeroshell kicks in at an altitude of 80 miles (130 km) above the surface in order to decelerate from 10,000 to 1,000 miles per hour (16,000 to 1,600 km/h.)

2 PARACHUTES
At six miles (10 km) above the surface, the parachutes open to reduce the speed of the descent.

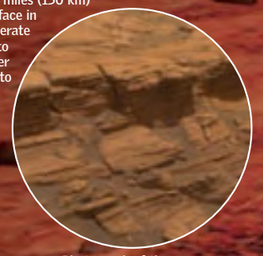
3 FALL
The entry module is separated from the shield that protected it from the heat.

4 ROCKETS
At 33 to 50 feet (10-15 m) above the surface, two rockets are ignited to slow the fall. Then the air bags are inflated to surround and protect the module.

5 AIR BAGS
The module and the air bags separate themselves from the parachutes and fall to the Martian soil.

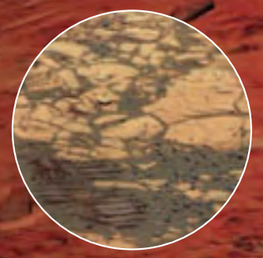
6 DESTINATION
The air bags deflate. The "petals" that protect the ship open. The vehicle exits.

7 INSTRUMENTS
The robot unfolds its solar panels, camera, and antenna mast.



Photograph of the surface taken by Spirit

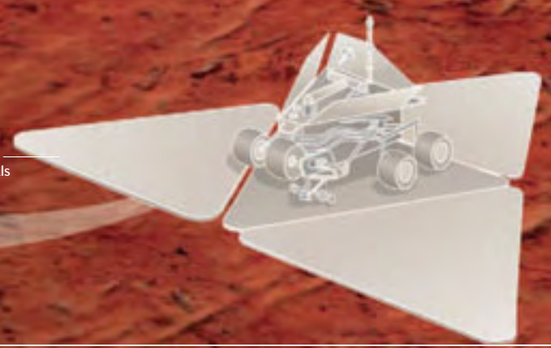
70,000 images
Obtained by Spirit in its first two years



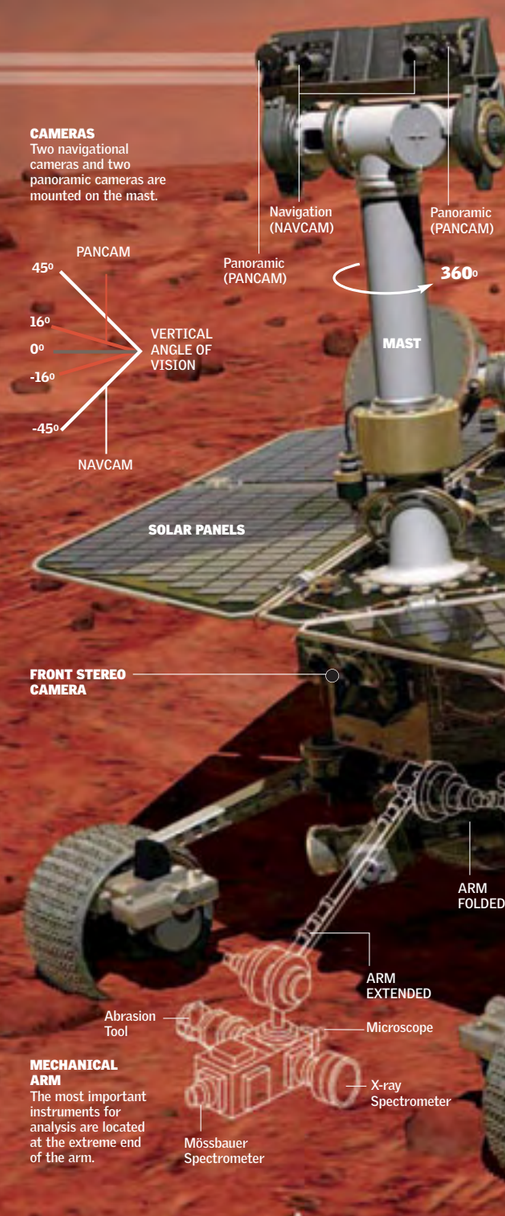
Track and photograph taken by Opportunity

80,000 images
Obtained by Opportunity in its first two years on Mars

The protective shield consists of three petals and a central base.



CAMERAS
Two navigational cameras and two panoramic cameras are mounted on the mast.



OMNIDIRECTIONAL SHORTWAVE ANTENNA
transmits the information gathered by the robot to the Control Center on Earth.

SOLAR PANELS
receive the light from the Sun and transform it into energy. The solar battery can function only with sunlight.

ELECTRONIC MODULE

UHF RADIO

INERTIAL MEASUREMENT UNIT
provides information on position relative to the x, y, and z axes.

Generates about 140 watts every four hours

ANTENNA

BATTERY

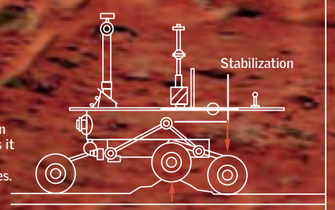
MECHANICAL ARM
The most important instruments for analysis are located at the extreme end of the arm.

2 inches/second (5 cm/s)
Maximum velocity of forward motion on level ground

MOTION AND PROPULSION

The robot has six wheels. Each one has an individual electric motor that allows it to make turns up to 360°, since both the two front wheels and the two rear wheels can be steered.

The propulsion system allows it to overcome small obstacles.



OPERATIONAL CYCLES
The robot is programmed to function in cycles of 30 seconds.

A Home in Space

To live in space for long periods, it is necessary to have an environment that compensates for the lack of oxygen. Space stations have systems that provide oxygen to the crew and filter out the exhaled carbon dioxide. Life in a space station allows astronomers to study the effect of a long-term stay in space. Space stations also have laboratories for conducting scientific experiments.

Space Giant

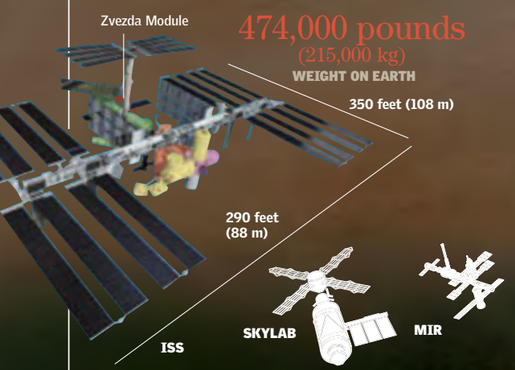
The International Space Station (ISS) is the result of the integration of NASA's Freedom and the Russian Space Agency's Mir 2 projects. Construction began in 1998, and the large illustration shows what the ISS will look like when it is finished in 2010. Various countries have contributed modules for the station. Its habitable surface area is equal to that of two Boeing 747s.

INTERNATIONAL SPACE STATION (ISS)

Habitable space	42,400 cubic feet (1,200 cu m)
Speed	17,200 mph (27,700 km/h)
Length	350 feet (108 m)
Panel surface area	43,000 square feet (4,000 sq m)
Laboratories	6

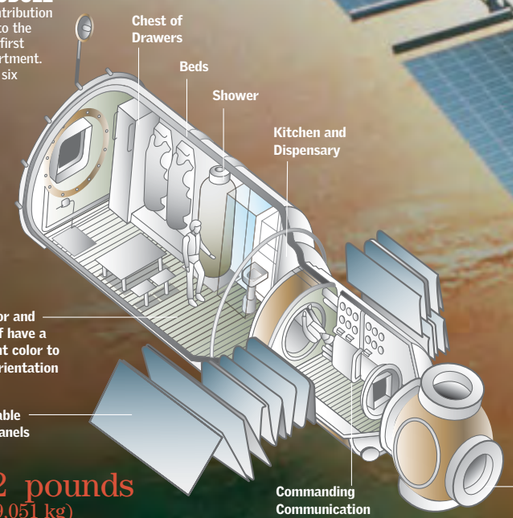
MANUFACTURER

USA. Russia Japan European Union

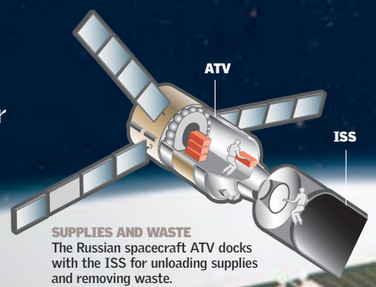


ORBIT
It carries out 16 orbits around the Earth each day at an altitude of 210 to 285 miles (335 to 460 km).

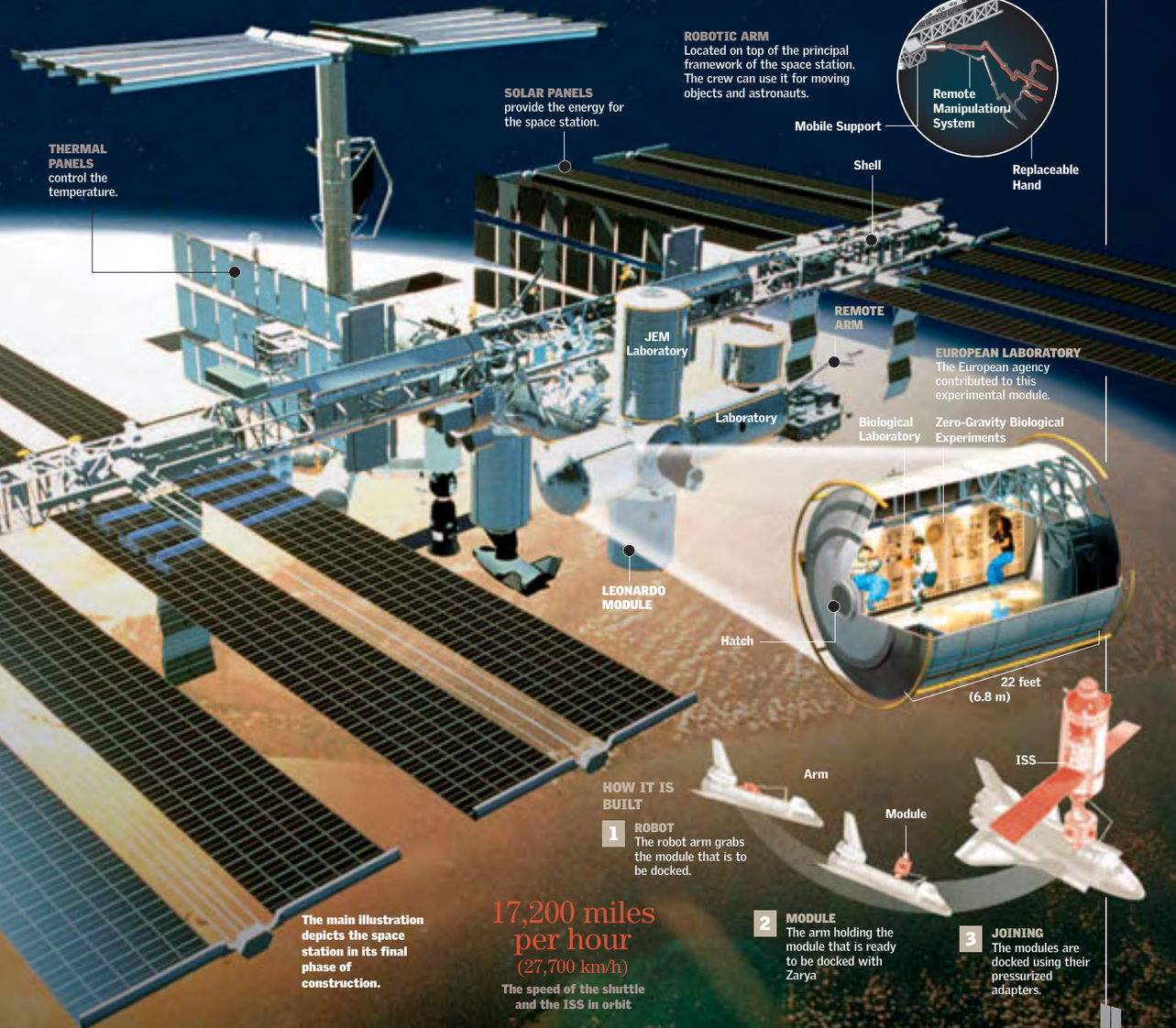
ZVEZDA MODULE
The principal contribution by the Russians to the station. It is the first habitable compartment. It holds three to six astronauts.



41,912 pounds
(19,051 kg)
WEIGHT ON EARTH



SUPPLIES AND WASTE
The Russian spacecraft ATV docks with the ISS for unloading supplies and removing waste.



The main illustration depicts the space station in its final phase of construction.

17,200 miles per hour
(27,700 km/h)
The speed of the shuttle and the ISS in orbit

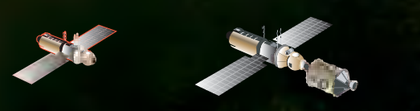
HOW IT IS BUILT

1 **ROBOT**
The robot arm grabs the module that is to be docked.

2 **MODULE**
The arm holding the module that is ready to be docked with Zarya

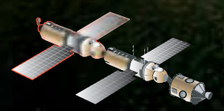
3 **JOINING**
The modules are docked using their pressurized adapters.

STAGES OF CONSTRUCTION



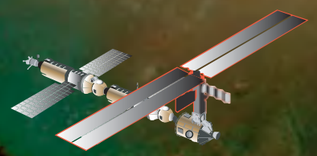
November 1998
Zarya Module
First section put into orbit. Provided energy in the first stages of ISS assembly.

December 1998
Unity Module
Connecting passage between the living and work area modules. Contributed by the European Union.

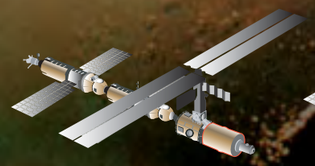


July 2000
Zvezda Module
The structural and functional center of the ISS. Entirely built and placed into orbit by the Russians.

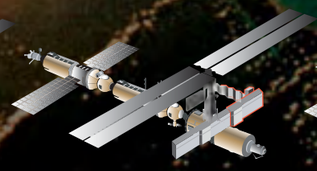
October 2000
Z1-Truss and Ku-Band Antenna
neutralize the static electricity generated in the ISS and allows communication with the Earth.



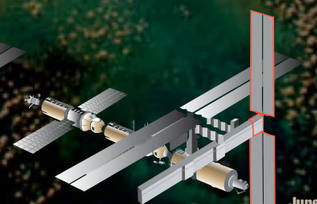
November 2000
P6 Truss
Structural module that has radiators for dissipating the heat generated in the station



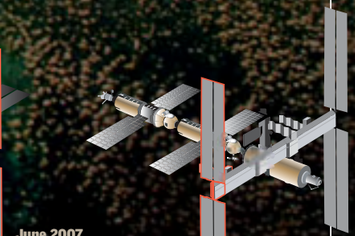
February 2001
Laboratory Destiny
Central section. This is where scientific experiments in microgravity environments are performed.



Novembre 2002
P1 Truss
The P1 truss was added opposite the S1 truss as part of the integrated truss assembly.



September 2006
P3/P4 Truss and Solar Arrays
The second port truss segment was added, and its solar panels were unfolded.



June 2007
S3/S4 Truss and Solar Arrays
The second starboard truss segment was added, and its solar panels were unfolded.

Spying on the Universe

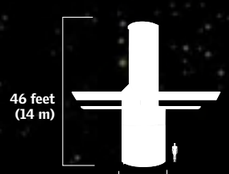
Space telescopes such as the Hubble are artificial satellites put into orbit for observing different regions of the universe. Unlike telescopes on Earth, space telescopes are above the Earth's atmosphere. Therefore, they avoid the effects of atmospheric turbulence, which degrades the quality of telescopic images. Moreover, the atmosphere prevents the observation of the stars and other objects in certain wavelengths (especially the infrared), which substantially decreases what might be seen in the heavens. Space telescopes do not have to contend with light pollution, which is a problem for observatories near urban areas.

The Hubble Space Telescope

The Hubble was put into orbit on April 25, 1990, by NASA and ESA. It is an artificial satellite whose instruments are directed toward outer space. The telescope can be remotely controlled by astronomers at different locations. The telescope's computers point the telescope in the desired direction, and sensitive light detectors and cameras make the desired observations, in many cases producing impressive vistas of the cosmos. In 1993, because of a fault in the primary mirror, a corrective lens called COSTAR had to be installed to correct the focus of the telescope.

TECHNICAL SPECIFICATIONS

Launch date	April 25, 1990
Orbital altitude	370 miles (600 km)
Orbital period	97 minutes
Type of telescope	Ritchey-Chretien Reflector
Organization	NASA and ESA
Useful life	20 years (until 2010)
Launch cost	$2 billion
Primary mirror diameter	8 feet (2.40 m)



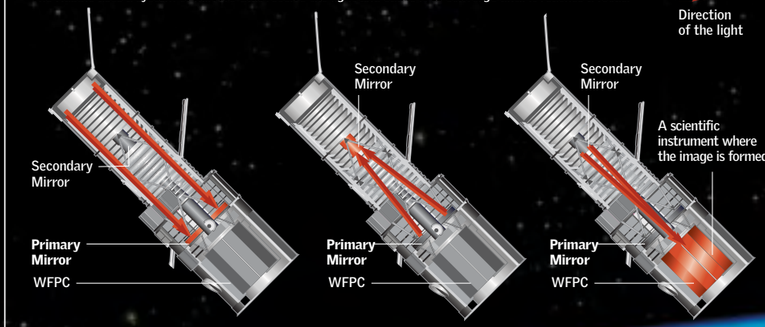
24,250 pounds (11,000 kg)
WEIGHT ON EARTH

SHUTTER
During observations it opens to allow light to enter.

SECONDARY MIRROR
Located inside the telescope tube. Light reflects from the secondary mirror to the camera.

HOW IT CAPTURES IMAGES

The Hubble uses a system of mirrors that receive the light and cause it to converge until it reaches a focus.

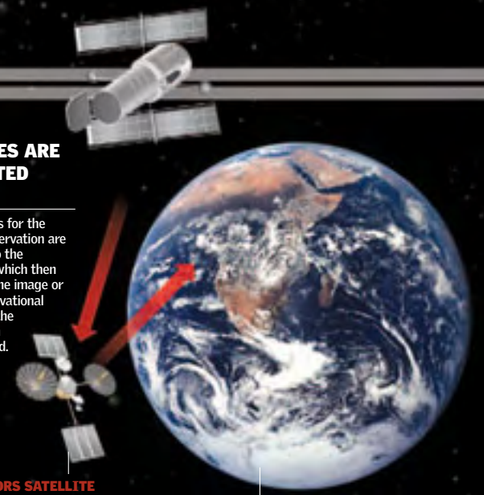


1 INCOMING LIGHT
The light enters through an aperture and is reflected in the primary mirror. Then the light converges toward a secondary mirror.

2 LIGHT REFLECTION
The rays coming from the primary mirror go to the secondary mirror, which reflects the light and returns it to the primary mirror.

3 IMAGE FORMED
The rays go through a hole in the primary mirror and are then concentrated in the focal plane, where they form an image.

HOW IMAGES ARE TRANSMITTED



1 HUBBLE
Instructions for the desired observation are uploaded to the telescope, which then transmits the image or other observational data after the observation is completed.

2 TDRS SATELLITE
Receives the data from Hubble and sends them to a receiving antenna at the White Sands Test Facility in New Mexico.

3 EARTH
From New Mexico, data are transmitted to the Goddard Space Flight Center in Greenbelt, Maryland, where the information is analyzed.

IMAGES
The Hubble can photograph a large variety of objects—from galaxies and clusters of galaxies to stars on the verge of exploding (such as Eta Carinae) and planetary nebulae (such as the Cat's Eye).

STAR ETA CARINAE | SUPERNOVA | CAT'S EYE NEBULA

Because it is outside the atmosphere, Hubble photographs are sharper than those taken by terrestrial telescopes.

HIGH-GAIN ANTENNA
receives orders from the Earth and sends back as TV signals the photos that the Hubble takes.

EXTERNAL LAYER
protects the telescope from external damage. During repair missions, the astronauts inspect it to look for particles and debris to be removed.

SOLAR PANEL

PRIMARY, OR PRINCIPAL, MIRROR
is 8 feet (2.4 m) in diameter; captures and focuses the light.

SOLAR PANEL
Energy is provided by directional solar antennas that convert sunlight into electricity.

COSTAR
The optical device that corrected the defective original mirror of the Hubble. The device was put in place by space shuttle astronauts in 1993.

(WF/PC)
Primary electronic camera

ADVANCED CAMERA FOR SURVEYS

Other Telescopes

The Spitzer telescope, launched in August 2003, was designed to photograph very distant objects. It is expected to be deactivated in 2008. SOHO, developed jointly by NASA and ESA, shows in detail the interactions between the Sun and the Earth. Chandra, launched in 1999, carries instruments that provide information about the position and energy of celestial X-ray sources.

SPITZER
observes the universe in infrared.

SOHO
Put into orbit in 1995, it takes images of the Sun.

CHANDRA
The only X-ray observatory

Space Junk

Since the time that the first satellite (Sputnik) was launched in 1957, near space has become overcrowded with a large amount of debris. Satellite batteries that have exploded and parts of rockets and spacecraft still orbiting the Earth form a genuine cosmic garbage dump. These variously sized objects pose a danger to satellites and spacecraft because of the damage that would be caused by a collision—the particles move at speeds of 19,000 to 43,000 miles per hour (30,000 to 70,000 km/h).

Space Junk

Any object launched from Earth that is no longer useful but is still orbiting the Earth is considered space junk. Rockets used only once can remain in orbit, as do pieces of spacecraft or apparatuses ejected intentionally so that they would not enter the wrong orbit. Space junk can even include lost objects. In 1965 astronaut Edward White lost a glove, which kept orbiting the Earth for a month at 17,400 miles per hour (28,000 km/h).

SIZE OF SPACE JUNK

More than 11,000 objects and millions of tiny particles have been cataloged.

LESS THAN 0.4 INCH (1 CM)
Very small particles cause superficial damage.

30,000,000+

FROM 0.4 TO 4 INCHES (1-10 CM)
These particles can knock holes in satellites.

100,000+

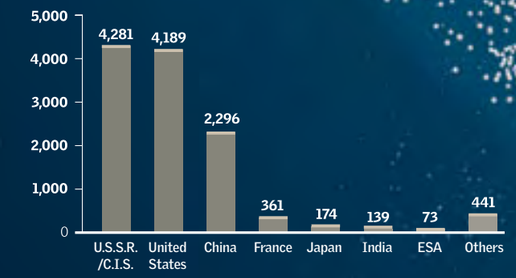
MORE THAN 4 INCHES (10 CM)
These objects can cause irreparable damage. These are the objects that are cataloged and tracked from Earth.

11,000+

OBJECTS IN SPACE BY COUNTRY

Since 1957, 25,000 objects have been launched into low orbit.

12,000
The approximate number of objects currently in orbit



What Can Be Done?

One course of action would be to ensure that the junk is returned to Earth and not allowed to orbit around it. But the most that has been done is to remove satellite remains from Earth orbit.

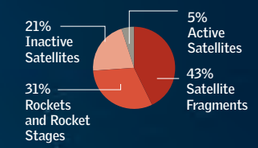
SAIL
The sail would be deployed when the satellite has stopped functioning. Solar wind would push the satellite out of its orbit.

SPACE PROBE
Impacts the satellite, changing its orbit and pushing it in a predetermined direction.

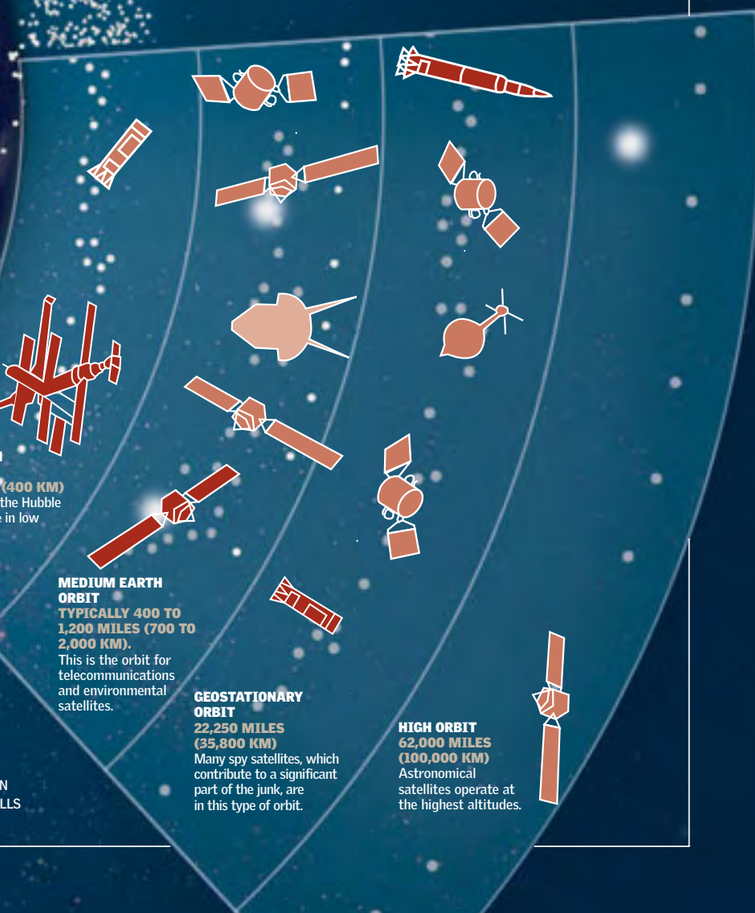
CABLE
A cable drags the satellite to lower orbits, and the satellite disintegrates when it enters the atmosphere.

ORIGIN AND LOCATION

Ninety-five percent of the objects in space around the Earth are junk. NASA is studying rockets that do not get into orbit but fall to Earth to avoid generating more junk.



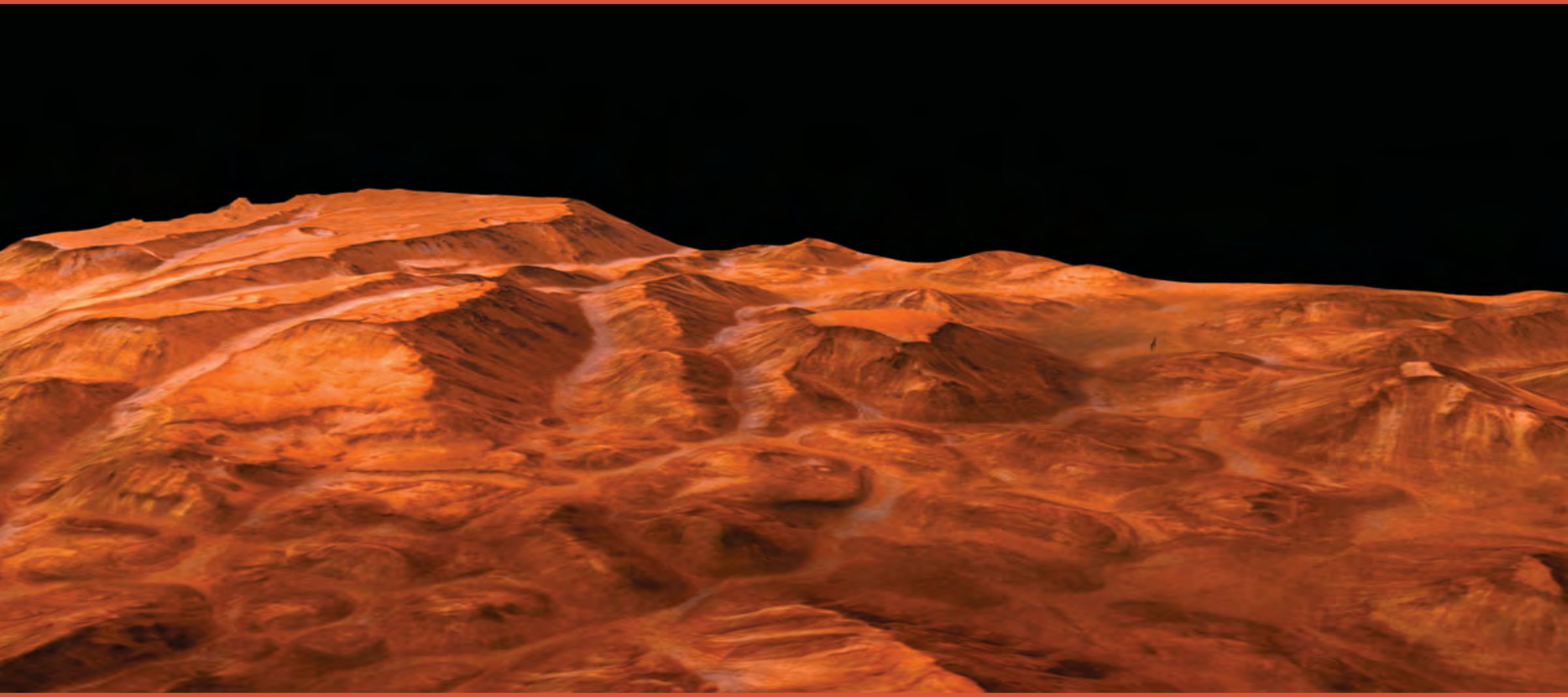
2,000 **tons of junk in less than 1,200 miles (2,000 km)**
Most of it consists of satellites that no longer operate and burnt-out stages of rockets.



Visiting Other Worlds

VALLES MARINERIS
The grand canyon of Mars is one of the most impressive geologic features of the entire solar system. It is some 2,400 miles (4,000 km) long and up to 6.2 miles (10 km) deep.

HUMAN TRACKS 64-65
MARS IN THE SIGHTS 66-67
JUPITER IN FOCUS 68-69
A VIEW OF SATURN 70-71
TOWARD VENUS AND PLUTO 72-73
CLOSER TO THE SUN 74-75
THE ROAD BEYOND 76-77



Space exploration has allowed us access to worlds believed to have been inaccessible, and it has also helped the human race to become conscious of the planet Earth and the need to care for it. The future of planetary exploration appears promising. The next few years will see ever more interesting discoveries. Right now there are spacecraft exploring or are on their way to explore other bodies of the solar system—Mars, Saturn, Jupiter, Venus, and even Pluto. The necessity of taking on large projects and traveling to sites ever farther away has always been with us. Therefore, each one of our accomplishments constitutes another step forward in our knowledge of space for the sake of all humanity. ●

Human Tracks

Ancient astronomers saw faint points of light that seemed to move among the stars. These objects were called planets, and each one of them was given the name of a god. In the 16th and 17th centuries, scientists came to recognize that the planets were physical bodies that revolved around the Sun. However, it was only recently, in the late 20th century, that technological advances permitted the direct study and the magnificent close-up photographs of the planets in the solar system.

The Planets

From the sightings by Galileo to the construction of space stations capable of sheltering humans, interest in revealing the mysteries of the planets has never ceased. Detailed studies of the rings of Saturn, the patches of ice at the poles of Mars, the exploration of various comets and asteroids, and the flybys of the great moons of the major planets are among the most striking results of space exploration to date.

Neptune
Visited only by Voyager 2, which took photographs in 1989

Pluto
Officially it is no longer considered a planet. Because of its small size, it has been called a dwarf planet since 2006.

Uranus
In 1986 Voyager 2 flew by Uranus and took photographs.

Saturn
The Voyager and Cassini-Huygens missions have studied its rings in detail.

TITAN
The Huygens probe landed on the surface of Titan, the largest moon of Saturn.

It is believed to be a frozen volcano.

Titan, a moon of Saturn

Enlarged area

Enlarged area

The atmosphere is in red.

The surface of the moon is in green and blue.

Jupiter
Some probes flew by the planet and took photographs. Galileo was in orbit for seven years, carrying out the most in-depth studies of its larger moons.

5 SUCCESSFUL MISSIONS

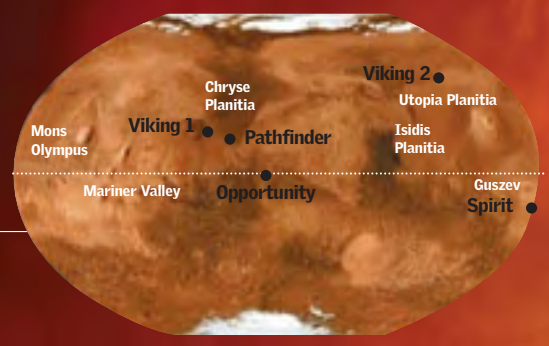
350 photographs
of Titan's atmosphere and surface were obtained by ESA.

Mars, the Most Visited
A Mars landing was the top priority of the space agencies. The Red Planet, the one that most resembles Earth, might harbor or could have harbored life, according to experts.

In total, there have been 38 missions to Mars, of which

16 WERE SUCCESSFUL

MARTIAN SURFACE

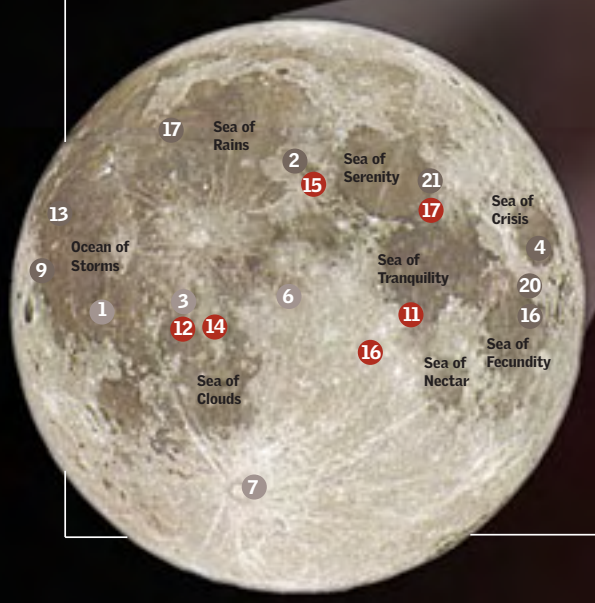


This is the place where the most significant Mars missions landed.

The Moon

The obsession to carry out successful missions to the Moon began with the programs of the Soviet Union at the end of the 1950s in the context of the space race with the United States. It was President John F. Kennedy who in 1963 announced that the United States intended to put a man on the Moon before the end of the decade. In 1969, Apollo 11 landed on the Moon, beginning a series of successful manned missions.

FACE OF THE MOON VISIBLE FROM THE EARTH



Earth
The International Space Station (ISS) orbits the Earth with astronauts onboard. They carry out various experiments. Space telescopes such as the Hubble also orbit the Earth.

Earth's Moon

Enlarged area

KEY

The most significant missions to land on the Moon

- XX Apollo
- XX Luna
- XX Surveyor

21 SUCCESSFUL LANDINGS ON THE MOON

Venus
The most important missions:
Venera (Soviet program), ESA's Venus Express, and Magellan (NASA)

12 MISSIONS LANDED ON VENUS.

The Sun

The Skylab space station obtained more than 150,000 images of the Sun between 1974 and 1979. The space probe Ulysses has studied the Sun's poles and the effects of its magnetic field. Its mission continues. The astronomical observatory SOHO is dedicated to studying the internal structure of the Sun and the origin of solar-wind particles. SOHO discovered 100 comets, including a number that crashed into the Sun.

Mercury
The Mariner 10 mission explored the planet, and Messenger will arrive there in 2011.

Mariner 10 was able to photograph

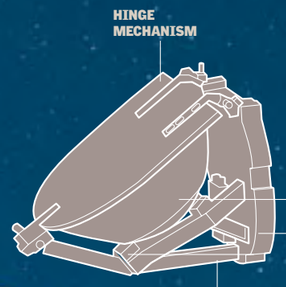
57 percent of the planet.

Mars in the Sights

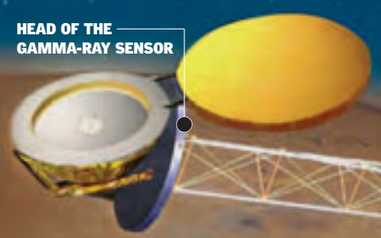
There was a time when it was thought that Mars, our closest neighbor, harbored life. Perhaps for this reason it is the planet that has been most explored by various spacecraft from the decade of the 1960s onward, and it is therefore the one we know the best, apart from the Earth. Mariner 9 in 1971 and Vikings 1 and 2 in 1976 revealed the existence of valleys and immense volcanic mountains. In 2001 the United States launched the Mars Odyssey mission, which indicated that liquid water exists at great depths.

Mars Odyssey Mission

Named after *2001: A Space Odyssey*, the probe was launched by NASA from Cape Canaveral on April 7, 2001. It entered into Martian orbit in October of the same year. The Mars Odyssey was designed for a number of functions, such as taking images in the visible and infrared spectrum, studying the chemical composition of the planet's surface, and investigating the existence of possible sources of heat. One of its purposes was also to find traces of hydrogen and thus water on Mars. Finally, the Mars Odyssey was used in support tasks for other Mars missions, acting as a radio-signal repeater between Earth and probes on the Martian surface.



GRS
Gamma-Ray Spectrometer
weighs 70 pounds (30 kg) and consumes 30 watts. It measures the abundance and distribution of 20 chemical elements on Mars.



LAUNCH
APRIL 7, 2001
The spacecraft Mars Odyssey is launched toward Mars atop a Delta 2 rocket.

MAY 2001
The spacecraft tests its cameras by sending an image of the Earth at a distance of 2 million miles (3 million km).

JUNE 2001
The gamma-ray spectrometer's protective hood is opened. The sensor begins to work.

JULY 2001
The probe activates its auxiliary engines to adjust its trajectory. The thrust lasts 23 seconds.

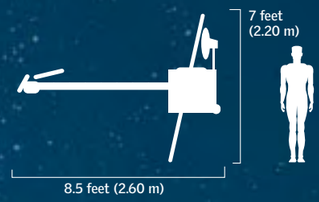
SEPTEMBER 2001
The probe begins to use the atmosphere to brake its speed, shape its orbit, and begin its mission.

MARS ARRIVAL
OCT. 24, 2001
The spacecraft Mars Odyssey reaches the orbit of Mars and begins its scientific studies.

CURRENT LOCATION OF THE ODYSSEY
It is orbiting Mars. It discovered the existence of ice, which was seen as a potential source of water for a future manned mission to the Red Planet.

TECHNICAL SPECIFICATIONS

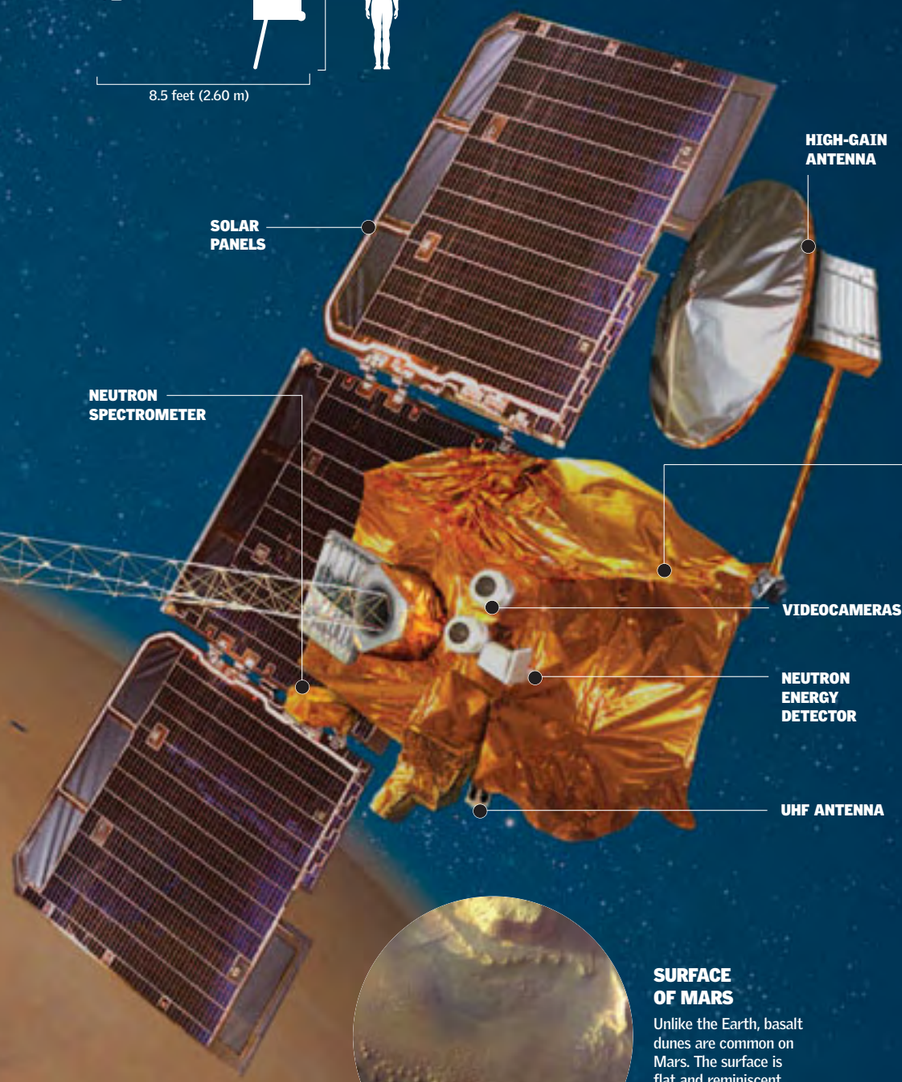
Launch	April 7, 2001
Arrived on Mars	Oct. 24, 2001
Cost of the mission	$332 million
Weight	1,600 pounds (725 kg)
Useful life	10 years



Earth Seen from Mars

Seen from Mars, the Earth is a magnificent blue star. From there, one can see the linked motions of the Earth and the Moon, as well as the combined phases of both. This photograph was taken by the Mars Odyssey in April 2006. Thanks to the spacecraft's infrared vision system, it was able to detect the temperatures on Earth, later confirmed by Earth-based sensors.

THE BLUE PLANET
A view of Earth from Mars as recorded by Mars Odyssey

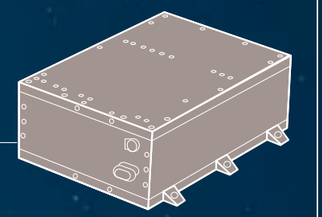


Discovery

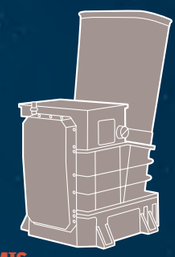
The new observations of Mars made by the Odyssey suggest that the north pole has about one third more underground ice than the south pole. Scientists also believe that microbial life could have developed on a planet other than Earth.

MARIE
An experiment measuring Mars's radiation environment

It weighs 7 pounds (3 kg) and consumes 7 watts. It is supposed to measure radiation produced by the Sun or other stars and celestial bodies that reach the orbit of Mars.

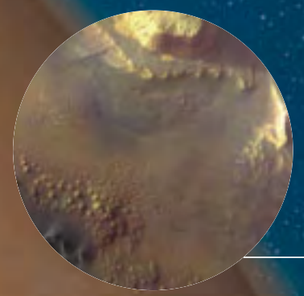


7 MONTHS
The time it took Mars Odyssey to reach its target



THEMIS
Thermal Emission Imaging System

Weighing 2,000 pounds (911 kg) and consuming 14 watts, this camera operates in the infrared spectrum. Its images allow conclusions to be drawn about the composition of the surface based on the spectrum of the infrared image and on the recorded temperature.



SURFACE OF MARS
Unlike the Earth, basalt dunes are common on Mars. The surface is flat and reminiscent of a desert.

Jupiter in Focus

The fifth planet of the solar system was visited by Pioneer 1 and 2, Voyager 1 and 2, and Cassini. However, the most significant visitor was Galileo, launched by NASA on Oct. 18, 1989. Galileo consisted of an orbiter and an atmospheric probe. After a long voyage, the atmospheric probe penetrated some 125 miles (200 km) into the atmosphere of Jupiter on Dec. 7, 1995, transmitting data about the atmosphere's chemical composition and Jupiter's meteorological activity. The orbiter continued sending information until it crashed into the gaseous giant on Sept. 21, 2003.

Trajectory

Galileo was designed to study the atmosphere of Jupiter, its satellites, and the magnetosphere of the planet. To get there, it did not use a direct path but had to perform an assisted trajectory, passing by Venus on Feb. 10, 1990. Then it flew by the Earth twice and arrived at Jupiter on Dec. 7, 1995. The probe succeeded in sending information of unprecedented quality with a low-gain antenna about the satellites of Jupiter, its moon Europa, and various examples of volcanic activity in its moon Io. It also contributed to the discovery of 21 new satellites around Jupiter. The mission was deactivated in 2003, and the vehicle was sent to crash into the planet. The purpose of this termination was to avoid future collision with its moon Europa that might have contaminated its ice; scientists believe that extraterrestrial microscopic life may have evolved on Europa.

ATMOSPHERIC PROBE
Released when Galileo arrived at Jupiter. It was used to study the planet's atmosphere.

LOW-GAIN ANTENNA

BOOSTERS

SOLAR PANEL

LOW-GAIN ANTENNA

MAGNETIC SENSORS.

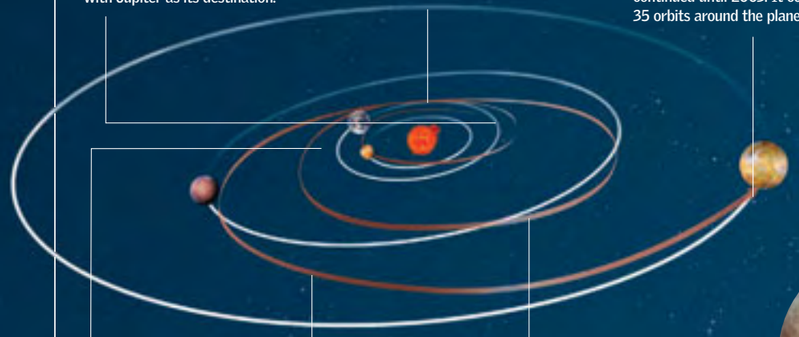
14 years

was the duration of the Galileo mission—from October 1989 to September 2003.

LAUNCH
OCT. 18, 1989
Galileo was launched by NASA from the space shuttle Atlantis with Jupiter as its destination.

EARTH FLYBYS
DECEMBER 1990/AUGUST 1992
Galileo passes by the Earth on two occasions to get the necessary boost toward Jupiter.

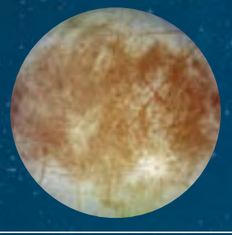
ARRIVAL AT JUPITER
DEC. 7, 1995
Galileo arrived at Jupiter and began the scientific studies that continued until 2003. It completed 35 orbits around the planet.



VENUS FLYBY
FEB. 10, 1990
Galileo transmitted data from Venus.

IDA FLYBY
AUG. 28, 1993
Galileo came close to the asteroid Ida.

GASPRA FLYBY
OCT. 29, 1991
Galileo approached the asteroid 951 Gaspra.



SURFACE OF EUROPA
The areas in red consist of dirty ice formed by water mixed with rocky material that slowly seeped into the ice and once there began to freeze. The "cracks" are caused by the breakup of the ice.

Galileo

In spite of its mission being plagued by technical problems, Galileo provided astronomers with a huge amount of information during its 35 orbits around Jupiter. The useful life of the probe, which cost $1.5 billion, extended five years longer than planned. The probe contributed to the discovery of 21 new satellites around Jupiter. Galileo sent large amounts of data and 14,000 images to Earth. It found traces of salt water on the surface of the moon Europa and evidence that it probably also exists on the moons Ganymede and Callisto. Likewise, it provided information about volcanic activity on the moon Io. It also showed an almost invisible ring around Jupiter consisting of meteorite dust. From the moment it was launched until its disintegration, the spacecraft traveled almost 2.9 billion miles (4.6 billion km) with barely 2,000 pounds (925 kg) of combustible fuel. More than 800 scientists worked on the project.

TECHNICAL SPECIFICATIONS

Date of arrival	Dec. 7, 1995
Cost of the mission	$1.5 billion
Useful life	14 years
Weight without the probe	4,900 pounds (2,223 kg)
Organization	NASA

ATMOSPHERE OF JUPITER
Composed of 90 percent hydrogen and 10 percent helium. The colors of the atmospheric clouds depend on their chemical composition. The clouds spread with the violent turbulence of the atmospheric winds.

IO
is one of the moons of Jupiter. It is notable for its brilliant color, which is caused by various sulfur compounds on its surface. Io is 417,000 miles (671,000 km) from Jupiter and was discovered by Galileo in 1610.

DESCENT TO JUPITER

1
Galileo released the atmospheric probe, which descended into Jupiter's atmosphere. The probe was provided with a deceleration and a descent module.

2
The deceleration module included protective heat shields and thermal control hardware for the phases of the mission leading up to the entry into the atmosphere.

DECELERATION MODULE

ANTENNA

PARACHUTES

DESCENT MODULE

3
A parachute 8 feet (2.5 m) in diameter was used to separate the descent module from the deceleration module and to control the velocity of the fall during the atmospheric descent phase.

PARACHUTES

4
The descent module carried six scientific instruments. During its 57 minutes of active life, the probe performed all the measurements and experiments that had been planned by the scientists.

Atmospheric Probe

Once Galileo arrived at the planet Jupiter, it released a small probe that fell through the atmosphere. This descent probe carried scientific instruments and the subsystems required to keep them active and transmit the data to the orbiter for storage for later transmittal to Earth. During its 57 minutes of active life in the Jovian atmosphere, the descent provided a number of discoveries, including a surprising lack of water in the upper layers of the Jovian clouds.

TECHNICAL SPECIFICATIONS

Entry into the atmosphere	Dec. 7, 1995
Active life	57 minutes
Weight	750 pounds (339 kg)
Organization	NASA

A View of Saturn

The longed–for return to Saturn was the result of a scientific alliance between NASA and the European Space Agency (ESA). On Oct. 15, 1997, after a number of years of development, the fruit of this collaboration lifted off toward this enormous gas giant. The mission of Cassini, the mother ship, was the exploration of Saturn. It carried a smaller probe, Huygens, that was to land on Saturn's largest moon, Titan, and transmit images and sounds from the surface. The Huygens probe accomplished this prodigious feat, demonstrating once again the capacity of humans to respond to the challenge of frontiers.

THE RINGS OF SATURN

are a conglomerate of ice particles and powdered rock orbiting the planet. The rings are 4.5 billion years old.

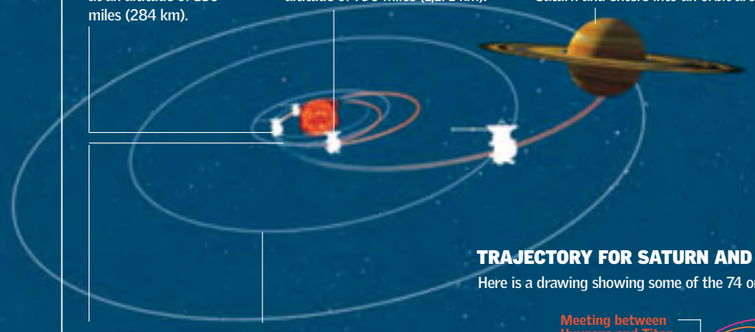
Trajectory

The trajectory of Cassini-Huygens was long and complicated, because it included strategic flybys of Venus (1998 and 1999), Earth (1999), and Jupiter (2000). Each one of these encounters was used to increase the craft's velocity and to send the spacecraft in the appropriate direction (a maneuver known as a gravity assist). Finally, and after almost seven years, traveling some 2.2 billion miles (3.5 billion km), the spacecraft arrived at its destination. It brought an end to the long wait since the last visit of a probe to Saturn—the 1981 flyby by Voyager 2.

VENUS 1
APRIL 1998
Cassini flies by Venus at an altitude of 180 miles (284 km).

THE EARTH
AUGUST 1999
Cassini flies by the Earth at an altitude of 730 miles (1,171 km).

SATURN
JUNE 2004
After seven years en route, Cassini arrives at Saturn and enters into an orbit around it.



VENUS 2
JUNE 1999
Cassini flies by Venus at an altitude of 380 miles (600 km).

JUPITER
DECEMBER 2000
Cassini flies by Jupiter at an altitude of 6,042,000 miles (9,723,896 km).

TRAJECTORY FOR SATURN AND TITAN

Here is a drawing showing some of the 74 orbits planned for the mission.

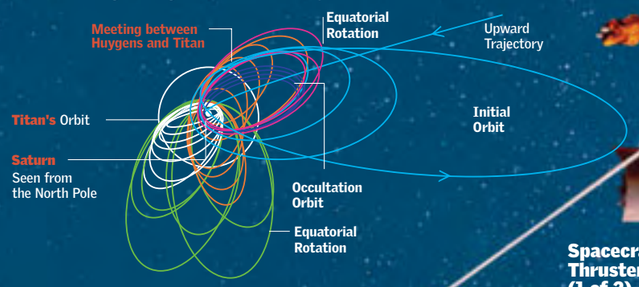


PHOTO OF JUPITER AND IO

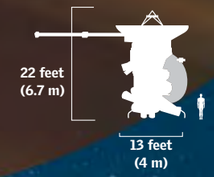
The moon Io, the closest to the planet Jupiter, is composed of a rocky silicate material. The nucleus has a radius of 560 miles (900 km) and may consist of iron. This is the photo taken by the Cassini probe.

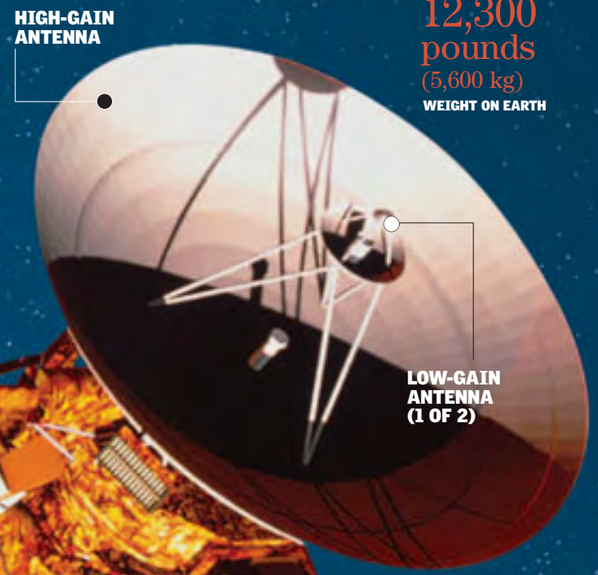
Cassini-Huygens

The information sent by Huygens and relayed by Cassini took 67 minutes to travel from Saturn to the Earth. Although it could only see a small section of Titan, the apparatus was able to answer some key questions. For example, the probe did not find liquid, but it did find signs that the surface had a crust that was hard on top and soft underneath, which was flooded from time to time. Investigators said that Titan could have very infrequent precipitation, but when it occurred it could be abundant and cause flooding. Moreover, it appears that some of the conditions for life to arise exist on Titan, although it is too cold for life to have started.

TECHNICAL SPECIFICATIONS

Date of launch	**Oct. 15, 1997**
Begins Saturn orbit	**July 1, 2004**
Closest approach	**11,800 miles (19,000 km)**
Weight	**12,300 pounds (5,600 kg)**
Organizations	**NASA and ESA**





12,300 pounds (5,600 kg)
WEIGHT ON EARTH

770 pounds (350 kg)
WEIGHT ON EARTH

Descent onto Titan

On Jan. 14, 2005, the six instruments of Huygens worked without pause during the two-and-a-half-hour descent. They confirmed, for example, that the gaseous blanket that surrounds Titan consists primarily of nitrogen and that its yellowish color is caused by the presence of complex hydrocarbons, which are formed when sunlight breaks down atmospheric methane. The thermometer measured –400° F (–203° C) at an altitude of 31 miles (50 km), which was the lowest temperature recorded during the entire mission.

1 SEPARATION
The Huygens probe separates from Cassini.

2 DESCENT
lasted 150 minutes and came within 790 miles (1,270 km) of the surface.

3 FIRST PARACHUTE
helped decelerate the probe during its fall.

4 SECOND PARACHUTE
replaced the first.

5 THIRD PARACHUTE
replaced the second.

6 DEPLOYS ITS LANDING FEET
The probe prepares for touchdown.

7 IMPACT ON THE SURFACE
The spacecraft strikes the surface of Titan..

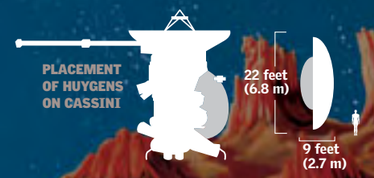
8 LANDING
The probe took photographs and data from the surface of Titan.

THE SURFACE OF TITAN

is obscured by a deep layer of clouds. It is possible that many chemical compounds similar to those that preceded life on Earth exist in a frozen state at high altitudes.

TECHNICAL SPECIFICATIONS: HUYGENS

Date of release	**Dec. 25, 2004**
Weight	**703 pounds (319 kg)**
Organizations	**NASA and ESA**
Date of landing	**Jan. 14, 2005**
Descent by parachute	**2.5 hours**

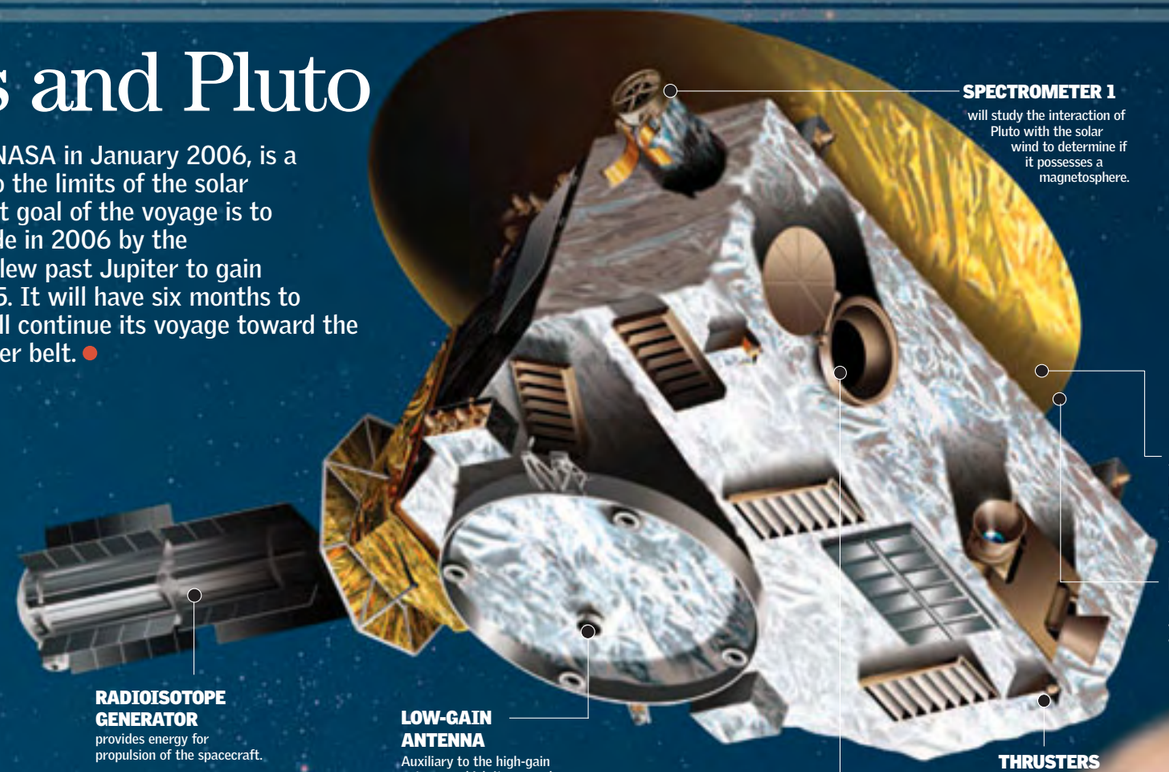


Toward Venus and Pluto

The New Horizons mission, launched by NASA in January 2006, is a voyage that will carry the spacecraft to the limits of the solar system and beyond. The most important goal of the voyage is to visit Pluto, a dwarf planet (a designation made in 2006 by the International Astronomical Union). The ship flew past Jupiter to gain enough speed to get to Pluto in the year 2015. It will have six months to make observations of Pluto, after which it will continue its voyage toward the region of the solar system known as the Kuiper belt.

New Horizons Mission

An unmanned space mission by NASA whose destination is to explore Pluto and the Kuiper belt. The probe was launched from Cape Canaveral on Jan. 19, 2006. It flew past Jupiter in February 2007 to take advantage of the planet's gravity and increase its speed. It will arrive at Pluto on July 14, 2015. Finally, the probe will fly by one or more objects in the Kuiper belt. The principal objectives of the mission are to study the form and structure of Pluto and its satellite Charon, analyze the variability of the temperature on Pluto's surface, look for additional satellites around Pluto, and obtain high-resolution images. The power source for the spacecraft is a radioisotope thermoelectric generator.



SPECTROMETER 1
will study the interaction of Pluto with the solar wind to determine if it possesses a magnetosphere.

RADIOISOTOPE GENERATOR
provides energy for propulsion of the spacecraft.

LOW-GAIN ANTENNA
Auxiliary to the high-gain antenna, which it can replace in case of breakdown

TELESCOPIC CAMERA
will map Pluto and gather high-quality geologic data.

THRUSTERS
The spacecraft carries six thrusters to increase its speed during flight.

The Spacecraft

The central structure of New Horizons is an aluminum cylinder that weighs 1,025 pounds (465 kg), of which 66 pounds (30 kg) are accounted for by scientific instruments. All its systems and devices have backups. The spacecraft carries a sophisticated guidance-and-control system for orientation. It has cameras to follow the stars and help find the right direction. These cameras have a star map with 3,000 stars stored in their memory. Ten times each second, one of the cameras takes a wide-angle image of space and compares it with the stored map.

ANTENNA
High-gain, 7 feet (2.2 m) in diameter, its purpose is to communicate with the Earth.

RADIOMETER
measures the atmospheric composition and temperature.

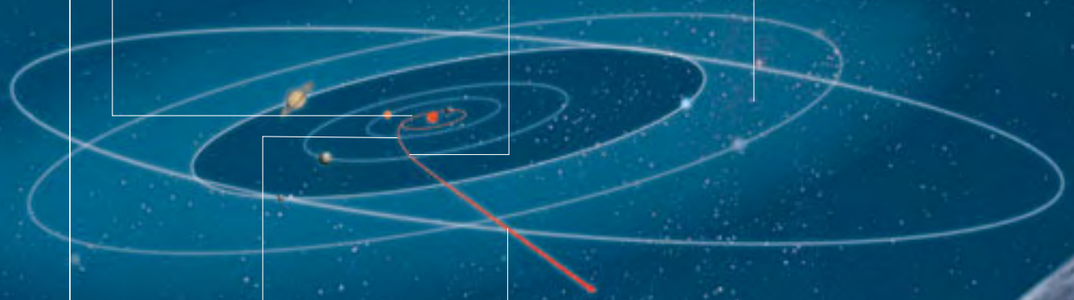
TECHNICAL SPECIFICATIONS

Launched	Jan. 19, 2006
Flyby	Pluto
Cost	$650 million
Weight	1,025 pounds (465 kg)
Organization	NASA

LAUNCH
JAN. 19, 2006
The New Horizons probe is launched from Cape Canaveral toward Jupiter, Pluto, and the Kuiper belt.

JUPITER FLYBY
FEBRUARY 2007
The probe flies by Jupiter to take advantage of the gravity of the planet on its journey toward Pluto.

KUIPER FLYBY
2016-20
The probe flies by one or more Kuiper belt objects.



INTERSECTING THE ORBIT OF MARS
APRIL 7, 2006
The probe traverses the Martian orbit.

ARRIVAL AT PLUTO
JULY 14, 2015
New Horizons flies by Pluto and its moon Charon. It sends to Earth data about the surface, the atmosphere, and the climate.

2015
The spacecraft New Horizons will arrive at Pluto on July 14, 2015.

The Venus Express Mission

Venus is a little smaller than the Earth and has a dense atmosphere. Because it is located at slightly more than 67 million miles (108 million km) from the Sun, it receives almost twice the solar energy as the surface of the Earth. The Venus Express is the first mission of the European Space Agency to Venus. The scientific aims include studying in detail the atmosphere, the plasma medium, the surface of the planet, and surface-atmosphere interactions. It was launched from the Baikonur cosmodrome on Nov. 9, 2005. The mission will last two Venus days, some 500 terrestrial days. The spacecraft entered into orbit on April 11, 2006.

LAUNCH
Nov. 9, 2005

ARRIVAL AT VENUS
April 11, 2006

STAY ON VENUS
500 terrestrial days

TECHNICAL SPECIFICATIONS

Launch	Nov. 9, 2005
Cost	$260 million
Weight	2,700 pounds (1,240 kg)
Organization	ESA

SPECTROMETER 1
measures the atmospheric temperature.

SPECTROMETER 2
operates on ultraviolet rays..

SOLAR PANELS
capture the energy from the Sun that powers the mission.

CAMERA
captures images in the ultraviolet.

MAGNETOMETER
measures magnetic fields and their direction.

HIGH-GAIN ANTENNA
transmits data to Earth.

Closer to the Sun

The space probe Ulysses was launched from the space shuttle on Oct. 6, 1990. It completed its first orbit around the Sun in 1997 and since then has carried out one of the most in-depth studies ever about our star. The probe's orbits allow it to study the heliosphere at all latitudes, from the equator to the poles, in both the northern and southern hemispheres of the Sun. The joint NASA and ESA mission is the first to orbit around the poles of the Sun. It orbits the Sun at 10 miles per second (15.4 km/s).

PASSES OVER THE SOLAR NORTH POLE
June-October 1995
September-December 2001
November 2007-January 2008

1 Beginning of the first orbit: **1992**

2 Beginning of the second orbit: **1998**

3 Beginning of the third orbit: **2004**

PASSES OVER THE SOLAR SOUTH POLE
June-November 1994 / September 2000
January 2001 / November 2006-April 2007

100 days

FIRST ORBIT

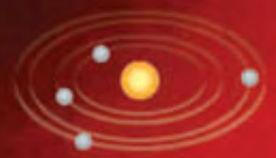
ORDER OF THE HELIOSPHERE
Ulysses completed its first solar orbit in December 1997 after having passed over the north pole. The heliosphere's structure was seen to be bimodal—that is, the solar winds were faster at greater inclinations of the orbit (beginning at 36°). During the first orbit, there was relatively little solar activity.

SECOND ORBIT

HELIOSPHERE CHAOS
The information obtained by the Ulysses probe in the year 2000 showed a structural change in the solar wind during the period of maximum solar activity. Ulysses did not detect patterns in which wind speed corresponded with inclination, and in general the solar wind was slower and more variable.

THIRD ORBIT

CHANGES IN THE MAGNETIC FIELD
After having survived the difficult pounding of the solar activity during its second orbit, the Ulysses probe began a third orbit around the Sun's poles in February 2007. Solar activity was expected to be at a minimum, as it was in 1994, but the poles of the magnetic field are reversed.



SWOOPS
An instrument that studies the ionic composition of the solar wind and the particle material

DUST
An internal device to study the energy composition of the heliosphere's particles and cosmic dust.

RADIAL ANTENNA
contains four devices for different experiments.

GRM
A device that studies the gamma rays emitted by the Sun

VHM
A device for studying the magnetic field of the heliosphere

URAP
is used to measure the radio waves and plasma in the solar wind.

HI-SCALE
Device designed to measure the energy present in ions and electrons of the interplanetary medium

HIGH-GAIN ANTENNA
The antenna is used for communication with Earth stations.

REACTION TANK
A tank of fuel used for correcting the probe's orbit

ANTENNA CABLE CONTROL
A device onboard the spacecraft to change the position of the antennas

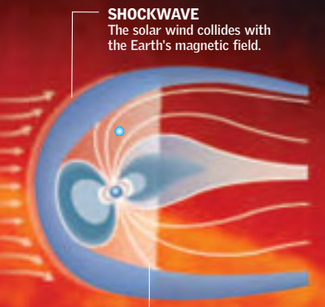
GOLD COVERING
It serves as insulation to help maintain the spacecraft's instruments at a temperature below 95° F (35° C) while the fuel is kept at a temperature above 41° F (5° C).

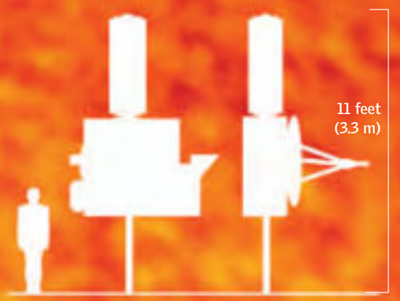
ANTENNA CABLE
There is one on each side of the spacecraft. They are deployed after liftoff.

THERMOELECTRIC RADIOISOTOPE GENERATOR
provides electric energy for propelling the spacecraft in space.

Solar Wind and the Earth

Thanks to its intense nuclear activity the Sun expels a million tons of particles per second into space. This particle flow forms a low-density plasma that extends the Sun's magnetic field and interacts with the Earth's magnetosphere. The area where the solar wind no longer has an effect is called the heliopause.





TECHNICAL SPECIFICATIONS: ULYSSES

Launch date	Oct. 6, 1990
Weight when launched	815 pounds (370 kg)
Weight of the instruments	1,200 pounds (550 kg)
Orbital inclination	80.2° with respect to the ecliptic
Organization	NASA and ESA (joint mission)

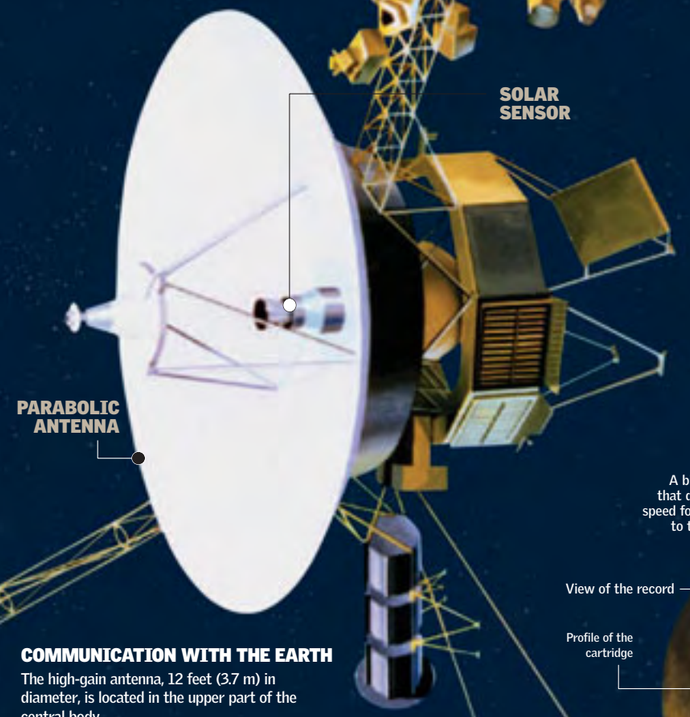
10 miles (15.4 km) per second
THE VELOCITY REACHED BY THE ULYSSES PROBE

The Road Beyond

The space probes Voyager 1 and 2 were launched by NASA to study the outer solar system. Voyager 1 was launched on Sept. 5, 1977, and flew by Jupiter in 1979 and Saturn in 1980. Voyager 2 lifted off on Aug. 20, 1977, then flew by Jupiter and Saturn to reach Uranus in 1986 and Neptune in 1989. Voyager 2 is the only probe that has visited both of these planets. Both probes have now become the furthest distant artificial instruments ever sent into space by humans.

PIONEER 10 AND 11

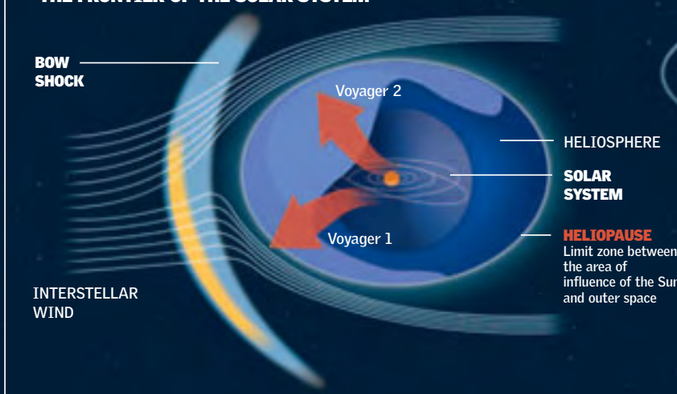
In 1973 Pioneer 10 became the first spacecraft to fly by Jupiter. It was followed by Pioneer 11, which made a flyby of Jupiter in 1974 and Saturn in 1979. Pioneer 11 stopped working in 1995. Signals were received from Pioneer 10 until 2003.

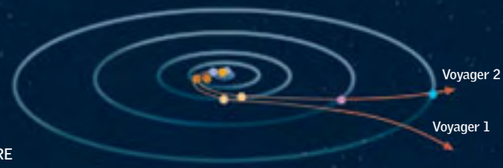


Golden Record

The Voyagers carried the recorded greetings of humanity in a golden, 12-inch record. Each spacecraft had one, with information about life on Earth, photographs, music of Mozart, Bach, and Beethoven, greetings in more than 50 languages, and the brain waves of a woman (Ann Druyan, the wife of the now-deceased astronomer Carl Sagan, who supervised this collection). If the message finds anyone who can respond, it will be, in the words of Sagan, "humanity's most important discovery."

THE FRONTIER OF THE SOLAR SYSTEM





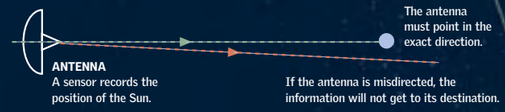
TRAJECTORY

The Voyager probe passed by Jupiter in 1979 and by Saturn in 1980. The Voyager 2 did the same and arrived at Uranus in 1986 and Neptune in 1989. Both are still active.

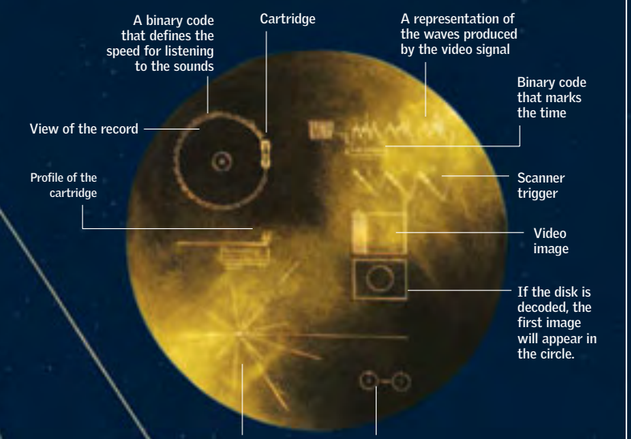
EARTH
JUPITER
SATURN
URANUS
NEPTUNE

COMMUNICATION WITH THE EARTH

The high-gain antenna, 12 feet (3.7 m) in diameter, is located in the upper part of the central body.



WHAT THE RECORD IS LIKE



Looking for the Heliopause

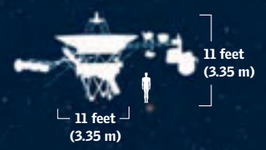
With Voyagers 1 and 2 leaving the Solar System, the project was renamed the Interstellar Voyager Mission. Both probes continue to study the magnetic fields they detect, looking for the heliopause—that is, the limit between the area of the Sun's influence and interstellar space. Once that frontier has been passed, the Voyagers will be able to measure waves that escape the solar magnetic field, beginning with the so-called "bow shock," a zone where the solar wind diminishes abruptly because of the disappearance of the solar magnetic field. It is hoped that the Voyagers will continue to be active for at least 30 years.

10,000 days

have passed since Voyager 1 was launched into space. During this time, it discovered 21 new satellites of the four planets studied; it proved that the rings of Saturn consist of particles of ice; it discovered the rings of Neptune; and it determined the character of the magnetic field of Uranus.

TECHNICAL SPECIFICATIONS: VOYAGER 1 AND 2

Launch date	**1977**
Useful life	**60 years**
Weight	**1,800 pounds (815 kg)**
Source of energy	**Plutonium**
Organization	**NASA**



1,800 pounds (815 kg)
WEIGHT ON EARTH

MILESTONES OF THE VOYAGE

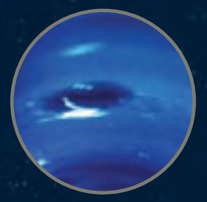
1977
LAUNCHES
The space probes Voyage 1 and 2 were launched by NASA from Cape Canaveral. They then began a long and successful mission that continues today.

1977
PHOTO OF THE EARTH AND THE MOON
On September 5, Voyager 1 sent photographs of the Earth and the Moon, demonstrating that it was working perfectly.

1986
ENCOUNTER WITH URANUS
On January 24, Voyager 2 arrived at Uranus. It sent photographs of the planet to the Earth and sent data on its satellites, rings, and magnetic fields.

1987
OBSERVATION OF A SUPERNOVA
Supernova 1987A appeared in the Large Magellanic Cloud. It was photographed with great clarity by the space probe Voyager 2.

1989
COLOR PHOTO OF NEPTUNE
Voyager 2 is the first space probe to observe Neptune. It also photographed its largest moon, Triton, from close up.



1998
PASSES PIONEER 10
Pioneer 10, launched in 1973, was the farthest spacecraft from Earth until Feb. 17, 1998, when Voyager 1, not launched until 1977 but traveling faster, passed Pioneer 10 in terms of distance.

Applied Astronautics

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A DIFFERENT VACATION 90-91

SPACESHIPONE
The first privately funded reusable spaceship in the world, it flew 10 times higher than the highest airplanes.

Space tourism is ready to take off, and in the next decades it will become an adventure within the reach of many pocketbooks. In 2004 SpaceShipOne became the first private manned vehicle to reach near outer space and to remain outside the atmosphere for three minutes. Then it made a problem-free landing in the California desert. The project cost $20 million and was financed by one of the founders of Microsoft. Some people are already making reservations to fly in the craft and experience microgravity. It bears mentioning that manned space programs led to the development of various technologies, including cordless devices, implanted cardiac defibrillators, and digital imaging, to mention just a few. ●

From Space to Home

Space has been a laboratory for investigating and developing new technologies and methods, the applications of which have found a place in daily life. Various devices, foods, clothes, materials, and utensils have been tested in space under extreme conditions and have become useful in improving our lives. Scientists say that the technological innovations of the next 50 years will change society in such a way that a change in overall thinking will be necessary to assimilate them.

Intelligent Clothing

Clothing with computers and other technological capabilities incorporated into them has passed from the fiction of futurist movies to a reality that is getting closer and closer. New clothing has been designed to demonstrate how electronics can transform something to wear into intelligent, biometric clothing that responds to surrounding environmental conditions and to the wearer's vital signs. Thanks to the new types of cloth, scientists are already talking about garments to prevent diseases.

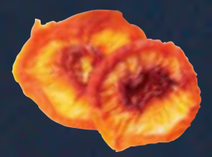
MAMAGOOSE

Mamagoose pajamas are used to monitor infants when they are at home sleeping. These pajamas have five sensors on the chest and stomach. Three of them monitor the heartbeat and the other two the respiration. The pajamas detect and warn of possible sudden infant death syndrome. The system is similar to the one used to continuously monitor the vital signs of the astronauts in space.

SENSORS ON:
- THE CHEST
- THE STOMACH

Domestic Uses

Frequent space travel has brought the application of new technologies to the home environment. Such is the case with microwave ovens and dehydrated food. It is only recently that they became part of the daily routine of the family in the home.



FOOD

The explorers dry their food and keep it in a cool place. The menu includes dried fruit, smoked turkey, flour tortillas, soy-milk cheese, walnuts, and peanuts.

MICROWAVE OVENS

Became popular in the United States in the 1970s. They allow rapid cooking or reheating of food thanks to the application of electromagnetic waves.

VELCRO

A system for rapidly joining and separating two parts that was created by George de Mestral in 1941

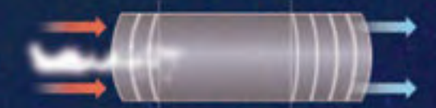
Air Purifiers

Air purifiers are designed to reduce the concentration of bacteria in the home and are beneficial for people suffering from allergies or asthma. Air purifiers are portable and can be carried from one room to another.

1 PHASE 1 The purifier takes in contaminated air with allergens.

2 PHASE 2 A filter processes the contaminated air.

3 PHASE 3 The purifier returns the pure air to the environment.



POLYCARBONATE

Compacted polycarbonate used in layers has high resistance to impact. It replaces glass and is also used in eyeglasses.

KEVLAR

A synthetic polyamide, used in especially protective clothing, such as bulletproof vests, equipment for extreme sports, and blankets.

SILICONE

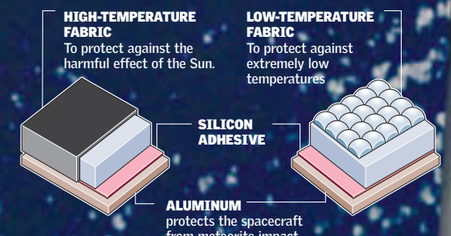
A polymer made of silicon. Used as a lubricants and adhesives and for waterproofing, ice-cube trays, and medical applications.

TEFLON

The common name of polytetrafluoroethylene. The special quality of this material is that it is almost inert—that is, it does not react with other chemical substances except under very special conditions. Another quality is its impermeability, maintaining its qualities in humid environments. Its best-known property is antisticking. It is used as a coating material on rockets and airplanes and, in the home, on frying pans.

SPACECRAFT PROTECTION

To withstand the effects of extreme temperatures and the collisions of meteorites, the spacecraft is protected by various layers that are bonded together with adhesive silicon. The exterior is made of aluminum. Next is a fabric that is resistant to very high temperatures, followed by a fabric to insulate against low temperatures.



BARCODE

provides information via a combination of parallel vertical lines that differ in thickness and spacing. Business and industry use a special scanner to read them.

Global Interconnection

Communications using satellites have made it possible to connect places that are very far from one another and to bring information to very remote regions. The satellites are primarily in geosynchronous orbits—that is, the satellite orbits in the same time it takes the Earth to rotate. This motion allows for more effective transmission systems, because the satellite is stationary with respect to the Earth's surface. There is a virtual fleet of geosynchronous satellites dedicated to various goals: meteorology, research, navigation, military uses, and, obviously, telecommunications.

Connections

Communication can be established between any two points on Earth. The signals sent and received between terrestrial and satellite antennas are in the radio-wave spectrum, and they range from telephone conversations and television to computer data. A call from Europe to the United States, for example, involves sending a signal to a terrestrial station, which retransmits the signal to a satellite. The satellite then retransmits the signal so that it can be received by an antenna in the United States for transmission to its final destination.

FIXED SENDING AND RECEIVING ANTENNA
can target specific places on the Earth.

TRANSPONDER
This is the heart of the satellite. It corrects for atmosphere-produced distortions of the radio signals.

SOLAR PANELS
take the light from the Sun and transform it into electrical energy.

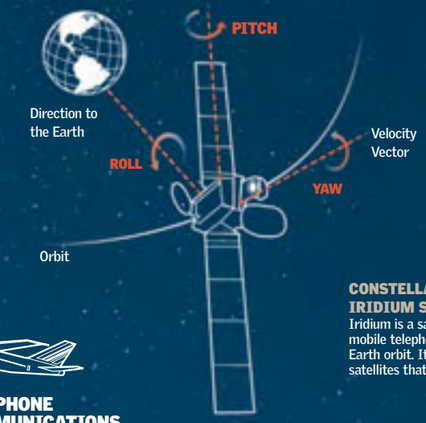
REFLECTOR
captures signals and retransmits them directly.

REFLECTOR

DOWNWARD LINK
The satellite retransmits signals to other points: a downward connection is made.

UPWARD LINK
The satellite captures signals that come from the Earth. An upward connection is made.

MOVEMENT ON THREE AXES
To correct its position, the satellite turns in three directions: an axis perpendicular to its orbit and the horizontal and vertical axes.



CONSTELLATION OF IRIDIUM SATELLITES
Iridium is a satellite-based, mobile telephone system in low Earth orbit. It consists of 66 satellites that follow a polar orbit.

TELEPHONE COMMUNICATIONS
are possible between an airplane and land by means of satellites.

Terrestrial Stations

These stations are buildings that house the antennas and all the necessary equipment on land for sending and receiving satellite signals. The buildings can be large structures, and the antennas can act as receivers and transmitters of thousands of streams of information. In other cases, they are small buildings equipped for communications but designed to operate on board ships or airplanes.

TRANSMITTING ANTENNA
The terrestrial antenna receives information from the satellite and retransmits it. This is the key for every kind of telecommunication.

TELEVISION BROADCAST CONNECTIONS
make it possible to transmit the news or other events via satellites that capture the signals and distribute them to different geographic locations.

NATIONAL TRANSMISSION GRID
Fixed structure on Earth that communicates with the antenna and receives information

TELEPHONY CONNECTION
A terrestrial antenna receives signals and transmits them to a center that resends to them in the corresponding format.

CENTER/ OPERATOR

PUBLIC NETWORK
For telephone communication between two points

PRIVATE NETWORK
Groups of private corporations, such as TV networks

PRIVATE
Private clients who pay for satellite access

MOBILE UNIT
Used for covering news or events that occur in different locations

Area of Maximum Power

Low-Power Boundaries

SATELLITE FOOTPRINT
Transmitted radio waves cover a defined area when they arrive at Earth. The area is known as a footprint.

TV
The signal arrives from the center via the antenna.

LAND LINE
The voice signal goes from the center to the desired location.

MOBILE TELEPHONES
can receive voice and images depending on the signal sent.

Global Satellite Navigation

The Global Positioning System (GPS), developed by the U.S. Department of Defense, makes it possible to determine the position of a person, a vehicle, or a ship anywhere in the world. The GPS system, which uses a constellation of two dozen Navstar satellites, became fully operational in 1995. Although it began as a military initiative, the GPS system was soon extended to commercial applications, which now include handheld navigation systems. A new development is the proposed European Galileo satellite navigation system, which resembles the GPS system but would use a constellation of 30 satellites. The European system is projected to become operational by 2013.

Operation

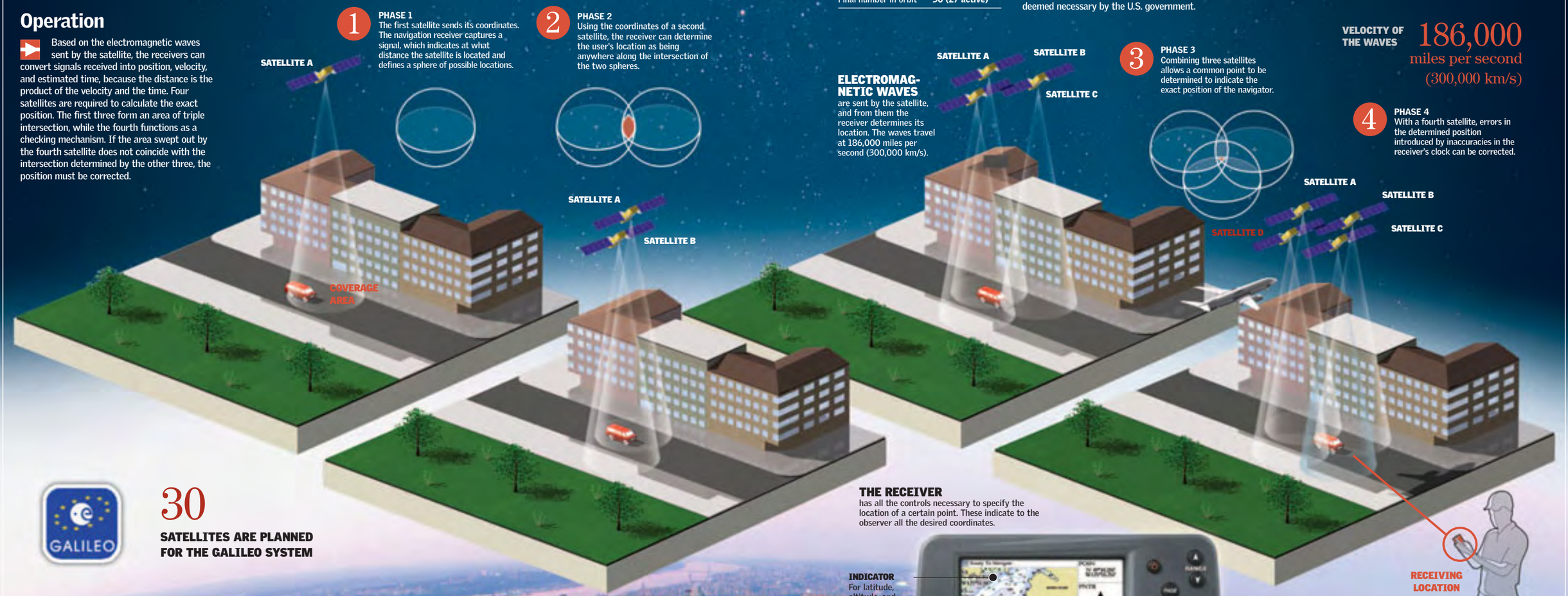
Based on the electromagnetic waves sent by the satellite, the receivers can convert signals received into position, velocity, and estimated time, because the distance is the product of the velocity and the time. Four satellites are required to calculate the exact position. The first three form an area of triple intersection, while the fourth functions as a checking mechanism. If the area swept out by the fourth satellite does not coincide with the intersection determined by the other three, the position must be corrected.

1 **PHASE 1**
The first satellite sends its coordinates. The navigation receiver captures a signal, which indicates at what distance the satellite is located and defines a sphere of possible locations.

2 **PHASE 2**
Using the coordinates of a second satellite, the receiver can determine the user's location as being anywhere along the intersection of the two spheres.

3 **PHASE 3**
Combining three satellites allows a common point to be determined to indicate the exact position of the navigator.

4 **PHASE 4**
With a fourth satellite, errors in the determined position introduced by inaccuracies in the receiver's clock can be corrected.



ELECTROMAGNETIC WAVES are sent by the satellite, and from them the receiver determines its location. The waves travel at 186,000 miles per second (300,000 km/s).

VELOCITY OF THE WAVES 186,000 miles per second (300,000 km/s)

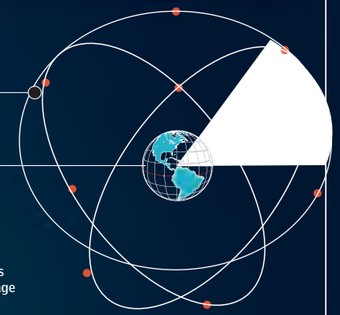
THE RECEIVER has all the controls necessary to specify the location of a certain point. These indicate to the observer all the desired coordinates.

TECHNICAL SPECIFICATIONS: GALILEO SATELLITE

First launched	2006
Orbital altitude	14,300 miles (23,000 km)
Orbital period	14 hours
Organization	European Union
Final number in orbit	30 (27 active)

Galileo System

The European Galileo project (which placed its first experimental satellite into orbit in late 2005) is a satellite navigation system that will be based on a constellation of 30 satellites (27 operational and 3 spares) in three medium Earth orbits in different planes to ensure global coverage. As with the GPS navigation system, it will permit a variety of applications in addition to navigation, such as the management of taxi fleets in large cities and the ability to locate stolen automobiles or other property. The Galileo project arose in part to gain independence from the GPS system, which could be interrupted or modified to be less accurate if deemed necessary by the U.S. government.



GALILEO ORBIT
The orbit of the satellites ensures sufficient coverage for calculating precise positions on the Earth.

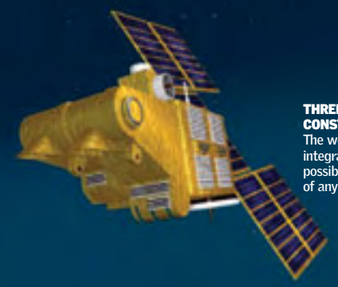
30
SATELLITES ARE PLANNED FOR THE GALILEO SYSTEM

Environmental Satellites

Spot 1 was put into orbit in 1986 with the sponsorship of the French Space Agency (CNES). It was the first satellite of what is today a constellation of satellites that can take photographs of different places on the Earth at very high resolution. Spot 5 can scan the Earth from three different angles, which makes it possible to construct three-dimensional images. Today Spot 5 is a commercial satellite par excellence, contracted by a variety of firms for close-up images. For example, agricultural firms request very close-up images of land under cultivation, and petroleum companies can request images for oil and gas exploration. Landsat, another satellite for monitoring the environment, was launched in 1999 and offers images of lower resolution.

Spot 5 Capabilities

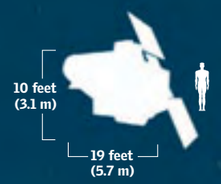
The development of the Spot satellite constellation has made it possible to commercialize photographic monitoring of environmentally linked phenomena. Using its scanning system, a Spot satellite can observe the same site every two or three days. Each satellite carries two cameras, which can provide side-by-side coverage for a track 73 miles (60 km) wide at ground level. Used in combination, the cameras can obtain a resolution as fine as 8 feet (2.5 m), or they can be aimed at different angles to produce stereoscopic images. The cameras can be used to produce black-and-white images or multispectral images that combine more than one wavelength of light. Depending on the area, Spot Image, the company that markets Spot images, can guarantee pictures without cloud cover. This is particularly valuable for applications that require images without clouds, fog, mist, or sandstorms.

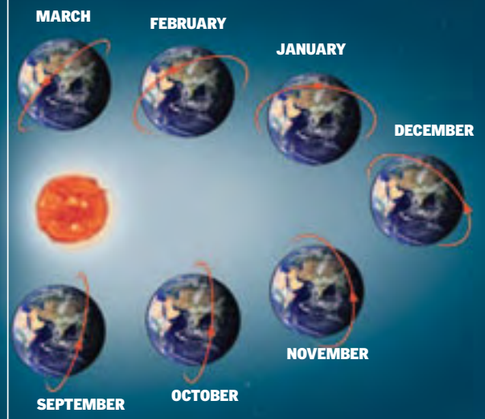


THREE-SATELLITE CONSTELLATION
The work is done in an integrated manner so that it is possible to obtain a daily picture of any point on the globe.

TECHNICAL SPECIFICATIONS

Launch date	May 4, 2002
Orbital altitude	520 miles (832 km)
Orbital period	100 minutes
Maximum resolution	8 feet (2.5 m)
Organization	CNES



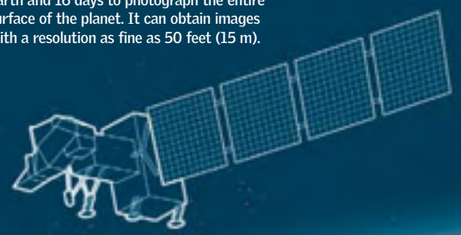


HELIOSYNCHRONOUS ORBIT

In order to compare the observations of a given point taken on different days, the images must be taken in similar lighting conditions. For this reason, the satellites are in heliosynchronous orbit, which means the plane of the orbit maintains a fixed angle with the Sun. As a result, each satellite has a view of the entire surface of the Earth over a 26-day period.

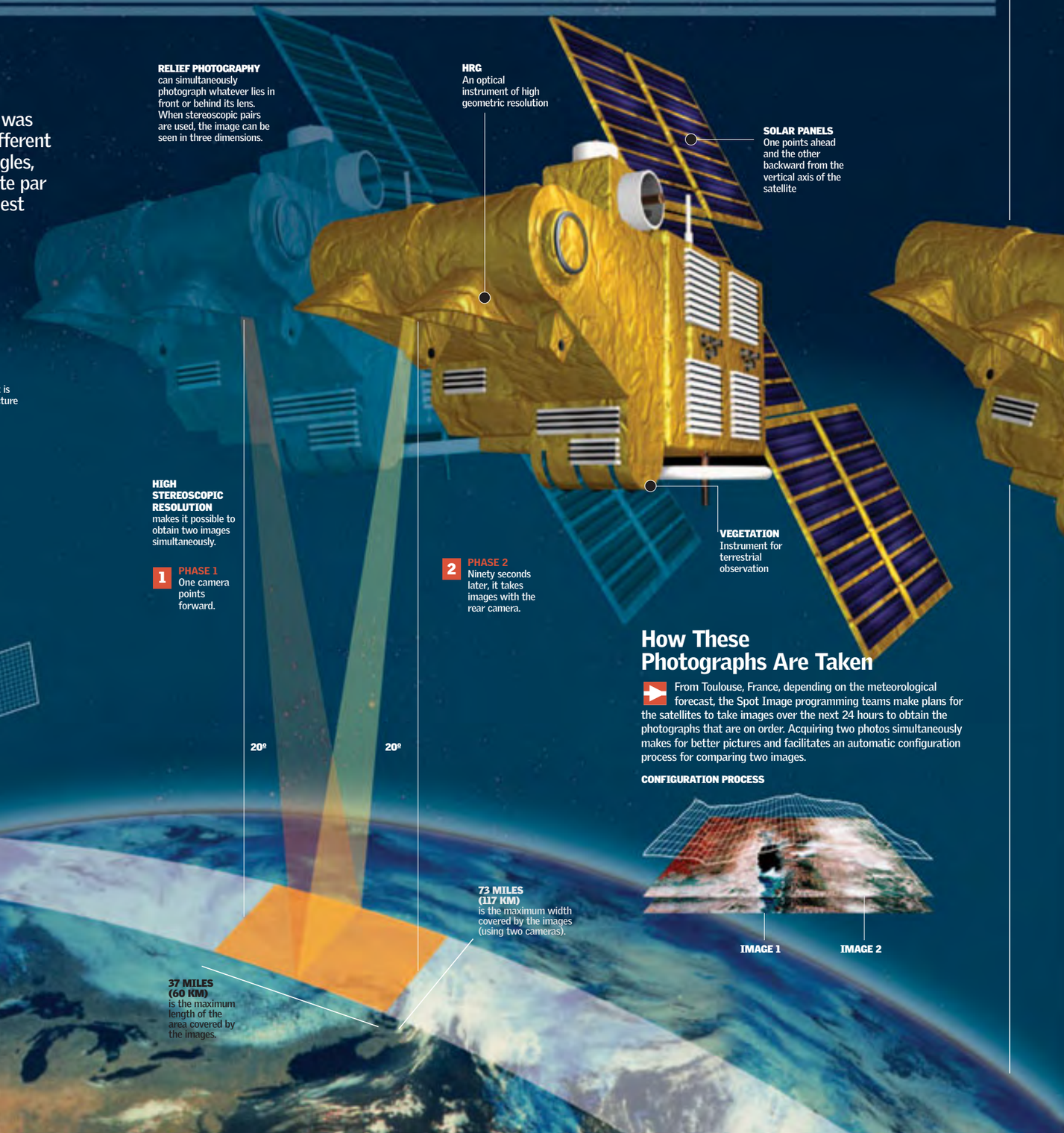
U.S. Satellite

Landsat 7 was launched by NASA in April 1999. It orbits the Earth at an altitude of 440 miles (705 km). It takes only 99 minutes to make one complete orbit of the Earth and 16 days to photograph the entire surface of the planet. It can obtain images with a resolution as fine as 50 feet (15 m).



LANDSAT 7
produces multispectral images of the Earth that are used to monitor changes in climate and the environment.

95%
of the surface of the Earth can be observed on any day by one of the three satellites.



How These Photographs Are Taken

From Toulouse, France, depending on the meteorological forecast, the Spot Image programming teams make plans for the satellites to take images over the next 24 hours to obtain the photographs that are on order. Acquiring two photos simultaneously makes for better pictures and facilitates an automatic configuration process for comparing two images.

CONFIGURATION PROCESS

From the Air

Photographs taken by Spot 5 can show the geography of any region of the world in different scales, from images of 8 feet (2.5 m) on Earth to fringe areas 37 miles (60 km) wide. Spot 5's high-definition capacity makes in-depth close-ups possible; it can target very specific places, from areas of vegetation to harbors, oceans, geographic borders, and forest-fire zones. Here Israel and its border regions—with Syria, Lebanon, and Egypt—together with the Dead Sea and the Golan Heights were photographed by the satellite, offering a panoramic image with significant detail.

ISRAEL

Latitude 32.98º

Longitude 35.57º

Surface area	8,500 square miles (21,946 sq km)
Population	6,116,533 (2003)
Population density	755 per square mile (302/sq km)
Capital	Jerusalem
Currency	Shekel

1,400 square (3,600 sq km) miles

The maximum surface area attainable by Spot 5 photos. It can do so both on local scales (for which finer resolution is used) and on regional scales.

Haifa

SEA OF GALILEE

Syria

Nazareth

THE DEAD SEA AS TAKEN BY LANDSAT 7

The North American satellite took this photograph of the Dead Sea in February 1975. The image combines optical and infrared techniques (in this wavelength range, water is seen as black). The Dead Sea is in the center, between Israel (on the left) and Jordan (on the right). North is up.

The West Bank

Its desert characteristics are observable in the color photograph taken by Spot 5.

JORDAN RIVER

Tel Aviv

The surface of the desert appears brown.

The Dead Sea is the lowest body of water in the world, 1,300 feet (400 m) below sea level. Its water evaporates rapidly in the desert climate, leaving behind dissolved minerals.

The vegetation is seen in green.

THE JUDEAN DESERT

The image shows different elevations and terrain with significant detail. The region of Sodom, 1,270 feet (387 m) below sea level, is the lowest place on the planet.

Jerusalem

Israel

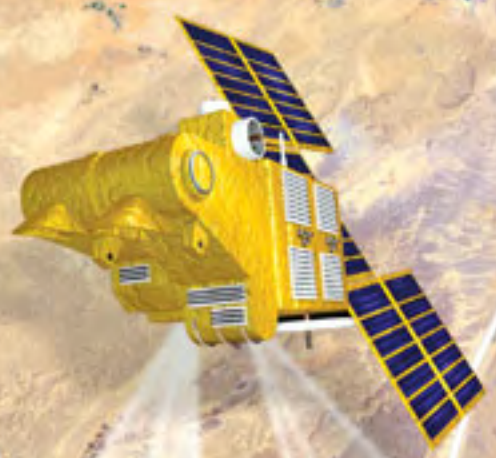
DEAD SEA

MEDITERRANEAN SEA

Gaza

Image Resolution

Technological developments have permitted increased resolution of what is called the image capture of geographic space. The maximum definition possible is 8 feet (2.5 m) on the Earth's surface. In some cases it is better to use resolutions of 16, 32, and 66 feet (5, 10, and 20 m). The pictures provided by Spot can cover an areas as much as 37 miles (60 km) wide and can be used for checking harvests, evaluating natural catastrophes, and checking demographic growth.



Satellite	Size of the pixel	Image
Spot 1 to 3	32 feet (10 m)	Color and B&W
	66 feet (20 m)	Color
Spot 4	16 feet (5 m)	Color and B&W
	32 feet (10 m)	Color
Spot 5	8 feet (2.5 m)	Color or B&W
	16 feet (5 m)	Color or B&W
	32 feet (10 m)	Color or B&W

Jordan

3-D images

Spot 5's scanning method makes it possible to construct images (primarily topographical relief) in three dimensions

Egypt

8 feet (2.5 m)

is the finest resolution attainable by the Spot 5 satellite and is capable of showing the details of a ship in a port.

0 miles (km) 6 (10)

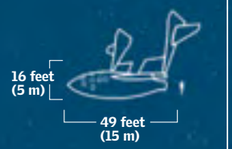
A Different Vacation

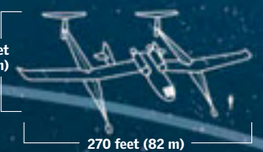
Perhaps a few years from now traveling to the edge of space will be another option for a vacation. Right now various private enterprises already have plans to offer this type of recreation. In April 2001 an American businessman, Dennis Tito, made a successful trip to the International Space Station. The first commercial space traveler, he paid $20 million for an eight-day stay. One year later, the Australian Mark Shuttleworth did the same. Then came the formation of SpaceShipOne, which has the potential of allowing thousands of tourists to travel to space at moderate cost.

DENNIS TITO

TECHNICAL SPECIFICATIONS: SPACESHIPONE

Date of launch	June 2004
Maximum altitude	about 62 miles (100 km)
First pilot	Mike Melvill
Enterprise	Private





TECHNICAL SPECIFICATIONS: WHITE KNIGHT

Launch date	June 2004
Maximum altitude	9.5 miles (15.24 km)
First pilot	Mike Melvill
Enterprise	Private

The Voyage

Suborbital flights are less expensive than orbital flights. The voyage typically lasts about two hours at a maximum velocity of 2,225 miles per hour (3,580 km/h) and a maximum altitude of approximately 60 miles (100 km). The stay in outer space lasts only a few minutes, during which time the traveler can see the beautiful profile of the Earth and experience the effects of microgravity. Such flights might become available to paying passengers.

$200,000
ANTICIPATED COST OF THE SUBORBITAL FLIGHT

4 days
OF TRAINING

2 hours
FLIGHT DURATION

WEIGHT OF THE SPACESHIP

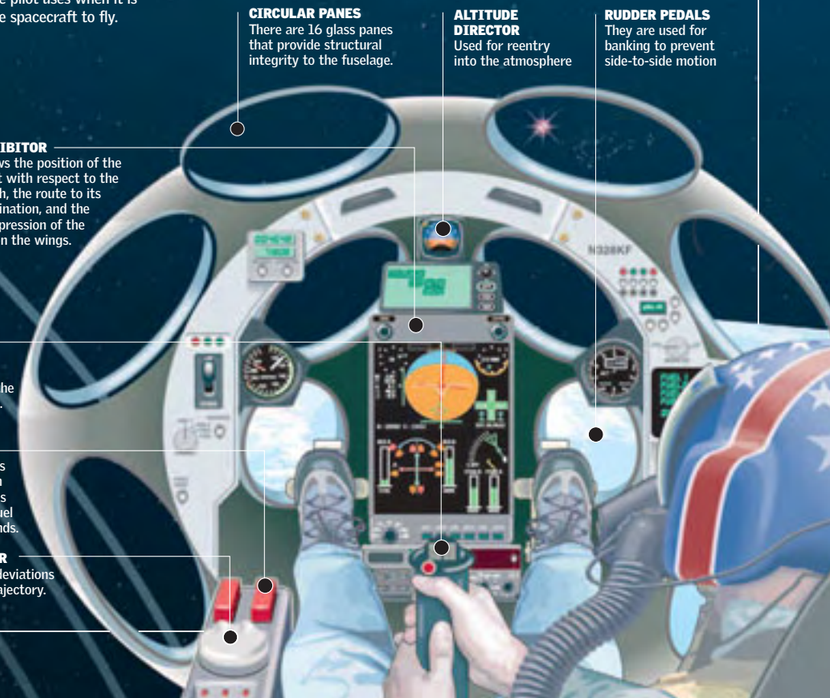
8,100 pounds
(3,670 kg)

The Cockpit

Equipped with advanced technology that permits the pilot to maneuver the spacecraft safely. It has 16 circular glass panes for a panoramic view of space and the Earth below. A central stick and rudder pedals are the principal controls the pilot uses when it is time for the spacecraft to fly.

THE CREW

Equipped with pressurized suits. The crew is trained for the flight and sits at the rear of the craft.



Glossary

Antenna

Dish or mast for receiving or sending radio signals.

Applications Satellite

Type of unmanned satellite for commercial use and for scientists who study the Earth. Application satellites can be broadly classified as communications, environmental, or navigational.

Artificial Intelligence

In general, the capacity of a machine to act like an intelligent being.

Astronaut

Person sent into space. To be able to perform tasks in space, astronauts wear pressurized suits. The training program is difficult and exhaustive.

Astronautics

Science that studies the design, construction, and function of spacecraft and the problems related to interplanetary space navigation. It also refers to related technologies.

Booster Rocket

Rocket that is attached to a primary rocket to increase thrust at liftoff.

Console

Instrument panel with controls and displays. The space shuttle contains a command console in the flight deck.

Depressurized

To remove or lose the air pressure within an enclosed area. For example, air locks are depressurized when astronauts in space suits prepare to exit the lock and leave the spacecraft.

Digital Signal

A signal that provides information numerically, such as a series of on-off values. Computers use digital signals that are typically represented by electric signals formed by a series of high or low voltage levels. Digital electronic equipment represents continually varying (analog) information as a series of discrete values.

Docking Adapter

The part of the spacecraft designed to join with another spacecraft when they are docked together.

Docking Port

A door that can be opened between two docked spacecraft so that the members of the crew can move from one to the other.

Energy Matrix

Also known as the solar matrix, it provides electric energy to the ionic motor of the spacecraft. They are less expensive than solar panels and also more resistant to space radiation.

Environmental Satellites

Satellites that gather environmental information about the Earth, such as images of the storms in the atmosphere, ocean temperatures and currents, and snow and ice cover. Images of the Earth's surface in different wavelengths can help evaluate the composition of rocks and the health of crops and other vegetation.

ESA

European Space Agency. It was established on May 31, 1975, with its principal headquarters in Paris.

Fuel

Substance that burns to provide energy. Some types of rocket fuel are liquid; other types are solid or rubbery. Rocket fuel burns with an oxidizer, producing gases that are expelled through the nozzles to provide thrust. Rockets carry their own oxidizer so that they burn fuel and provide propulsion in outer space, where there is no air.

Helmet

A space-suit helmet is made of strong plastic. The helmet contains a valve to let in oxygen and remove carbon dioxide. The helmet is airtight and contains communication gear, such as a microphone and headphones.

Infrared Radiation

Light with wavelengths somewhat longer than those of red light in the visible spectrum. It is invisible to the human eye. Infrared light can be readily used for transmitting information between two devices that are in close proximity to each other without their having to be connected by cables. Infrared radiation requires less energy to produce than visible light and does not interfere with light.

Image Spectrometer

Image spectrometer is a type of camera that records a digital image in two or more specific wavelengths, such as infrared and ultraviolet. The images can then be evaluated to obtain information about materials, such as the composition of rocks in an image of the Earth's surface.

Laser

Device that produces coherent light—that is, light composed of a single wavelength and in phase with each other. Lasers can be built from a variety of substances (such as ruby and certain gases), which are then stimulated electrically to produce a laser beam. Laser beams can have many uses. Intense beams can cut materials with great precision. Laser light is also used for transmitting digital information, because it can be readily generated in very short pulses.

Life-Support System

Equipment that provides air, water, and heat so that the astronauts can live in space.

Lock

Chamber of the spacecraft with an interior door connecting the cabin to another, outside door that opens into space. The members of the crew typically put their space suits on in the lock. If they did not use the lock, all the air from the spacecraft would escape.

Lunar Vehicle

Battery-powered vehicle used to drive over the lunar surface.

Manned Maneuvering Unit

Apparatus that astronauts formerly used to perform work, such as capturing satellites and testing new equipment, outside the spacecraft. It consisted of a framework with small directional thrusters.

Mariner

A series of U.S. space probes for the study of the interior planets of the solar system (Mercury, Venus, Mars). None was designed to land on a planet. In spite of the relative limitations of these missions compared to later probes, they contributed important planetary information that was used for later, more complex missions, such as the Viking.

Mars Pathfinder

U.S. space probe that successfully landed on Mars on July 4, 1997, in the area called Ares Vallis.

Messages from the Earth

Space probes on missions that carry them beyond the solar system have carried messages from the Earth to possible extraterrestrials who might find them. Discs and plates have been used to record information about the Earth and its life-forms with maps, images, and sounds.

Microelectronics

Miniaturized semiconductor electronic circuits have revolutionized spacecraft systems from control and navigation to communications.

Microgravity

The condition in which objects experience no or virtually no gravitational effects. It is associated with weightlessness. Many experiments conducted by astronauts in space take advantage of the microgravity in orbit. Some such experiments concern creating new types of materials; others involve studying the effects of microgravity on plants or other living things.

Mission Control

Facility of a space agency for monitoring and controlling a spaceflight.

NASA

National Aeronautics and Space Administration, the U.S. organization in charge of space exploration. Its headquarters are in Washington, D.C. NASA was created in 1958 by President Dwight D. Eisenhower.

Navigation Systems

Traditional systems of spacecraft navigation tracked the spacecraft from the ground and depended on human controllers there. In modern autonomous navigation systems, the path of the spacecraft is calculated and corrected using images of the asteroids and stars taken by an onboard camera system, then combining the information with the navigation system.

Operations Center

The operations center of mission control that monitors spaceflights using telemetry technology, which allows technical aspects to be monitored in real time.

Opportunity

The second of two NASA rovers that landed on the surface of Mars in 2004.

Orbital Perturbations

There are many subtle effects that perturb the orbits of Earth satellites. Some of the factors are the asymmetry of the Earth's orbit, solar and lunar effects, atmospheric influences, and pressure from solar radiation.

Oxidizer

Chemical agent (normally a gas) that is burned together with the fuel to fire the rocket engine.

Parachute

A device made of a strong textile that opens up in the shape of a huge umbrella, used to slow the fall of astronauts or rockets.

Payload

Materials or scientific instruments transported into space by a manned or unmanned spacecraft that are not part of the launch vehicle itself.

Pressure Suit

An airtight, inflatable suit designed to protect the body from low pressure at high altitude or in space. A space suit is a type of pressure suit.

Propulsion System

The most common propulsion system used for rockets is chemical, driven by combustion. A chemical rocket engine carries both a fuel and an oxidizer, which together take up most of the volume of the rocket. The fuel burns when it is combined with the oxidizer, and the escaping gases produce the propulsion. Other types of rocket propulsion systems include the ion (electric) system in which electrically accelerated ions are discharged from the engine to produce thrust.

Radar

A system that emits radio waves and detects any echoes of those same waves. Given that radio waves travel at the velocity of light, the times involved can be very brief. Among the uses of radar are measuring distances, planet cartography, and the study of meteorology. A type of radar called Doppler radar can be used to determine the speed of moving objects that reflect the radio waves.

Reaction Control System

The propulsion system used to change the position of a spacecraft.

Reentry

The portion of spaceflight in which the spacecraft enters the atmosphere to return to Earth. As the spacecraft passes through the atmosphere, the

friction between the air molecules and the spacecraft causes intense heating. Therefore, the surface of the spacecraft is protected by a thermal shield constructed of plastic, metal, and ceramics. Some materials are designed to vaporize, dissipating the heat without harming the spacecraft or its crew.

Rescue Ball

The rescue ball was designed to help crew members without pressurized suits escape. It is made of space suit material and has an oxygen supply so that an astronaut could escape safely to another ship.

Robotic Manipulation System

Robotic arm installed in the space shuttle, used for tasks such as unloading the space shuttle's payload bay.

Robotics

Technology that designs machines capable of independently carrying out a number of tasks and adapting their actions to the requirements of the moment.

Rocket

Reaction engine that carries its own fuel and a source of oxygen so that it can function in space as well as in the atmosphere. It is driven by gases that exit from nozzles. Launch vehicles consist of various rocket stages and can make use of booster rockets. A rocket produces the kinetic energy necessary to send objects (such as manned spacecraft, artificial satellites, and space probes) into space. The most common type of rockets are chemical rockets, which may use liquid or solid fuels and oxidizers.

Satellite

Object that orbits a much larger object. Artificial satellites do not carry a crew. They orbit the Earth and carry out such functions as the transmission of telephone calls or information about meteorology.

Scientific Satellites

These compile information and carry out exact studies of the Sun, other stars, the Earth, and the space environment. Such satellites can gather data that cannot be obtained on the surface of the Earth because of the Earth's atmosphere.

Sensor

Device commonly used in scientific and other types of instruments aboard spacecraft for gathering data and information.

Solar Panel

Panel covered with solar cells. The cells collect sunlight and convert it into electricity, which can be used to operate the equipment within a spacecraft.

Soyuz

Series of both manned and unmanned Soviet and Russian spacecraft. The Soyuz replaced the Vostok in the mid-1970s. The Russians use new versions of the Soyuz for launchings to the International Space Station. The original Soyuz series of spacecraft was developed between 1967 and 1981 and was used for 41 launches. These capsules were replaced by the more modern Soyuz-T, launched 15 times between 1980 and 1986. The most recent generation is the Soyuz-TM, the first of which was launched in 1986.

Space Blanket

Layer of powdered metal on a plastic film applied as spacecraft insulation or to reflect radio signals. Blankets made of this material retain 80 percent of the body's heat.

Space Exploration

The era of space exploration began in 1957 with the launching of the first artificial satellite. From that time, many astronauts and robot craft have left the Earth to explore space. Twelve astronauts have even landed on the Moon. Space probes equipped with automatic instruments have visited many bodies of the solar system, including comets and asteroids as well as the planets and their moons.

Space Junk

Any artificial object orbiting the Earth in space that has no purpose. It includes such materials as big rocket fragments and small particles of paint. Space junk has been accumulating since the beginning of space exploration.

Space Missions

Space missions are organized by a number of space-exploration agencies, including NASA, the European Space Agency, and the Russian Space Agency. Spacecraft can be manned or unmanned. Voyages are planned years in advance. International teams construct rockets, satellites, and probes that carry out specific tasks, such as visiting a planet or constructing the International Space Station. Some spacecraft are part of a series, such as the Apollo lunar mission.

Space Probe

Unmanned spacecraft sent to gather information from planets and other bodies of the solar system. Some probes are limited to flying close to a planet. At a preset distance, the instruments are activated to record data. When the probe leaves the planet behind, the instruments are deactivated. Many probes have been sent to land on the surface of a body of the solar system. Such probes have been used to land on the Moon, Venus, Mars, and Saturn's moon Titan.

Space Shuttle

The first spacecraft capable of returning to the Earth on its own and being reused on multiple missions. Today the U.S. fleet has three shuttles: *Discovery*, *Atlantis*, and *Endeavour*. The *Challenger* and *Columbia* were both destroyed in accidents (in 1986 and 2003, respectively).

Space Station

A base designed to orbit the Earth for a long period of time. Crew members can live and work in the space station for several months.

Space Suit

A suit that allows the wearer to survive in space. It protects against too much or too little pressure and harmful radiation, and it also provides the oxygen necessary for breathing.

Space Tourism

Recreational space travel, which first came about as a project launched in August 1999 between the Space Adventures enterprise of the United States and a Russian entity. In April 2001 the American businessman Dennis Tito paid $20 million for a trip to the International Space Station as the first space tourist.

Space Underwear

Before astronauts put on a space suit, they put on an apparatus for collecting urine that has a tube going to a receptacle. Women wear short pants, which absorb the urine and conduct it to the receptacle. They also wear underclothes equipped with tubes of water to cool the astronaut.

Spacelab

Spacelab was the space station designed to fit within the payload bay of the space shuttle. The Spacelab project was begun with a 1973 agreement between the United States and the nations belonging to the ESA. The first flight occurred in November 1983. The Spacelab was lifted into space for the last time in November 1997, when the development of the International Space Station began.

Spirit

One of two robots—the other being Opportunity—that was launched in 2003 from Earth and that landed on Mars in 2004. They carefully explored the surface of the planet. Both vehicles are part of the NASA Mars Exploration Rovers mission. They have tools that allow them to gather rocks and take soil samples to be analyzed for chemical composition. The robots are located on opposite sides of the Red Planet so that they can photographically study very different places.

Sputnik

Satellite that inaugurated the age of space exploration. Sputnik 1, launched in 1957, was an aluminum sphere 23 inches (58 cm) in diameter. Its instrumentation sent back information about cosmic radiation, meteorites, and the density and temperature of the Earth's upper atmosphere for 21 days. Sputnik 2 was the first to lift a living being, the dog Laika, into space.

Suborbital Flights

Flight designed to reach space but not achieve orbit. A typical suborbital flight lasts about two hours and reaches a speed of 2,220 miles per hour (3,580 km/h) and an altitude of about 62 miles (100 km). The time spent in space lasts only a few minutes.

Telescope

Instrument for magnifying the image of distant objects. Astronomical telescopes are used for observing the stars, planets, and other celestial bodies. The term is used to refer to instruments that magnify an optical image or an image produced by other types of electromagnetic radiation, such as radio waves. The Hubble Space Telescope is an orbiting telescope that can make observations free from the distorting effects of the atmosphere.

Thermal Insulator

Material that conducts heat poorly. It is used to protect the walls of a rocket from the high temperatures produced by burning fuel and to protect the skin of a spacecraft from the heat produced by air friction during reentry into the atmosphere.

Training

The astronaut training program takes several months. Regardless of educational background, trainees must study mathematics, meteorology, astronomy, physics, and space navigation. They regularly work in flight simulators and receive training in the use of the spacecraft computers and other equipment.

Viking

NASA sent the Viking 1 and Viking 2 probes to Mars in 1975. Both probes landed on the planet and carried out observations from its surface.

Vostok

Soviet space program that put a total of six cosmonauts into orbit around the Earth between April 1961 and June 1963. The first astronaut to orbit the Earth—at an altitude of 195 miles (315 km)—was Yury Gagarin, the only crew member of the Vostok 1.

Voyager 1 and 2

The space probes Voyager 1 and 2 were sent by NASA to study the outer solar system. Voyager 1 was launched in 1977, passed Jupiter in 1979, and passed Saturn in 1980. Voyager 2 was also launched in 1977; it passed by Jupiter and Saturn to reach Uranus in 1986 and Neptune in 1989. Both probes are heading out of the solar system and have provided data about the far reaches of the solar system.

X-rays

In November 1895 William Roentgen, when studying the production of electron beams known as cathode rays, became aware of a mysterious type of radiation that had not been observed before, and he called it X-rays. Astronomy has been strongly influenced by Roentgen's discovery in spite of the fact that X-rays coming from celestial objects cannot penetrate the Earth's atmosphere.

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